AN ASSESSMENT OF THE CHANGE IN TEMPERATURE AND PRECIPITATION IN ALBERTA

Alberta
ENVIRONMENT

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Prepared for:

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ABSTRACT

This statistical study assesses the change of Alberta climate using the monthly data of the following climate variables: 1) surface air maximum temperature, 2) surface air minimum temperature, 3) total precipitation, 4) total rainfall, and 5) total snowfall. The study period is 1884 – 1996 using data from 38 long-term climate stations in Alberta. The weighted average of individual station values was used to obtain an Alberta average of climate variables for each month. Both uniform weights (for the arithmetic mean or uniform average) and optimal weights (for the optimal average) were used. The optimal average, in contrast with the uniform average, is a more appropriate integral measure for a climate data field. The Alberta averages were smoothed using an eleven-year running mean to reveal the pattern of variation in time. Based on the running means of optimal averages, it was observed that the maximum temperature does not have an upward trend, whereas the minimum temperature has a clear upward trend of approximately 0.8 degree C since about 1920. Total annual precipitation appears to increase slightly since the 1920s. However, the data are much more variable and statistical testing is need to confirm the results.

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ACKNOWLEDGEMENTS

Terry Thompson of the University of Alberta, and the Hydrological Sciences Branch of Alberta Environmental Protection facilitated the acquisition of the Environment Canada monthly climate data set. Bin Shen wrote all the computer programs. Reviews by the staff of the Atmospheric and Hydrologic Sciences Division, Prairie and Northern Region, Environment Canada are greatly appreciated. Randy Angle and Elliot Kerr of Alberta Environmental Protection also contributed substantially to this project in terms of scientific discussions and review of drafts.

INTRODUCTION

Studies have shown that global average temperature has increased by as much as 0.6 degree C over the last 130 years (IPCC, 1996). The trends of temperature and other climate variables over smaller areas are known to vary greatly from place to place. The purpose of the present study is to examine the trends of climate variables, such as temperature and precipitation, over the province of Alberta and apply an averaging method that would provide a better representation of Alberta's climatic trends.

The spatial averages of climate variables are commonly used parameters to represent the state of the climate over an area. A common use of these averages is in the estimation of climatic trends. The simplest approach is to use the arithmetic mean over the stations. In the present study, an optimal averaging method is applied over Alberta, incorporating the variance-covariance structure among long-term Alberta climate stations. Climatic trends were then computed using this optimal average to provide an integral measure of climatic variation over the province. The optimal average incorporates the effect of the distribution of climate stations and considers the dependence of data from adjacent sites.

For simplicity of presentation, the numerous graphs and tables are numbered and included in Appendix A. Only the more important ones are labelled alphabetically and contained in the main text.

CLIMATE DATA

In the present study, 38 long-term stations in Alberta were selected for analysis. These are listed in Table 1. (See Appendix A.) The selection represents a reasonable cross-section of stations over Alberta. The regions represented include the North Saskatchewan River Basin (NSRB), the Red Deer River Basin (NDRB), the South Saskatchewan River Basin (SSRB), the Milk River Basin (MRB), the Rocky Mountains (ROCK), the Athabasca River Basin (ARB) and the Peace River Basin (PRB). The locations of the selected climate stations are shown in Figure 1.

The study period is 1884 to 1996 and monthly values were used. Of the 38 stations, the actual number of stations with data available varies over the study period. In general, the number of records increases with time from 1884 to the late 1980s and then decreases after 1990. This pattern is shown in Figures 2 to 3 for temperature and precipitation.

STATISTICS OF ALBERTA CLIMATE

Averages of Reference Period (1961-1990)

In the present study, only precipitation and temperature data were analyzed. The temperature variables are maximum, minimum temperatures and the precipitation variables are rainfall, snowfall and total precipitation observed. Total precipitation includes snowfall measurements converted to water equivalent. The climatic normals of temperature and precipitation are usually represented by the long-term averages computed over a period of 30 years, as adopted by the World Meteorological Organisation (WMO) and its member countries (IPCC, 1996). The long-term averages, or normals, for these variables at each of the selected stations were computed for each month using the 30 years of data from 1961 to 1990. This is also the official reference period used in the latest IPCC report (IPCC, 1996, p.141). These averages were used here as the measure of central tendency from which climatic variations were assessed.

The monthly averages of daily maximum temperature and daily minimum temperature over the reference period for the individual stations are listed in Tables 2 and 3. In addition to the latitudinal variation of maximum temperature, one can also see a smaller range of maximum temperature over the province in summer than in winter. For example, the largest difference (17.9 °C) in January is between Cardston (-0.3 °C) and Vermilion (-18.2 °C) whereas the largest difference (6.9 °C) in July is between Medicine Hat (27.3 °C) and Lake Louise (20.4 °C). The same seasonal variation also exists in the range of minimum temperature over the province. In this case, the January range is 15 °C between Cardston (-12,8 °C) and Fort Vermilion (-27.3 °C) and the July range is 8 °C between Medicine Hat and Lake Louise.

The precipitation data demonstrate high spatial and temporal variation. This is expected within the Province of Alberta with its diverse terrain and latitudinal extent. Annual rainfall of Rocky

Mountain House is about 1.5 times higher than that at Brooks and annual snowfall at Lake Louise is approximately 3 times higher than at Gleichen. The spatial and temporal variations of total precipitation are shown in Table 6.

The averages of temperatures and precipitation for Alberta over the reference period are shown in Figures A and B. The individual station averages vary to different degrees from these Alberta averages. A major consideration in the present study is to incorporate individual station variances and between station correlations of the climate variables, when computing the overall weighted means through the use of optimal weights. It will be shown that significant differences exist between the optimal average and the uniform average.

Variances

The variances of climatological data may not be entirely due to the natural climatic variation. Measurement and other errors also contribute to the variance of the observations. However, it is expected that the contribution of such errors is small relative to that from natural variability. Variances must be considered in computing the overall average of a climate variable for the province.

In the present study, the variance of the data is represented by the mean squared departure from climatology. The monthly anomalies were computed by subtracting the climatic normals (reference period averages) from the values observed. The sum of squares of the anomalies divided by the total number of records was used as the variance of the climate variable. This is slightly different from the usual statistical definition of variance, but is more meaningful in the present context because variability is expressed in terms of departures (anomalies) from the reference period climatological mean. The results are shown in Tables 7 through 11 for the temperature and precipitation variables.

The Alberta Average of Climate Variables

For an integral measure of a climate variable over a region such as the province of Alberta, it is necessary to convert the point measures of station observations to an areal measure for Alberta as

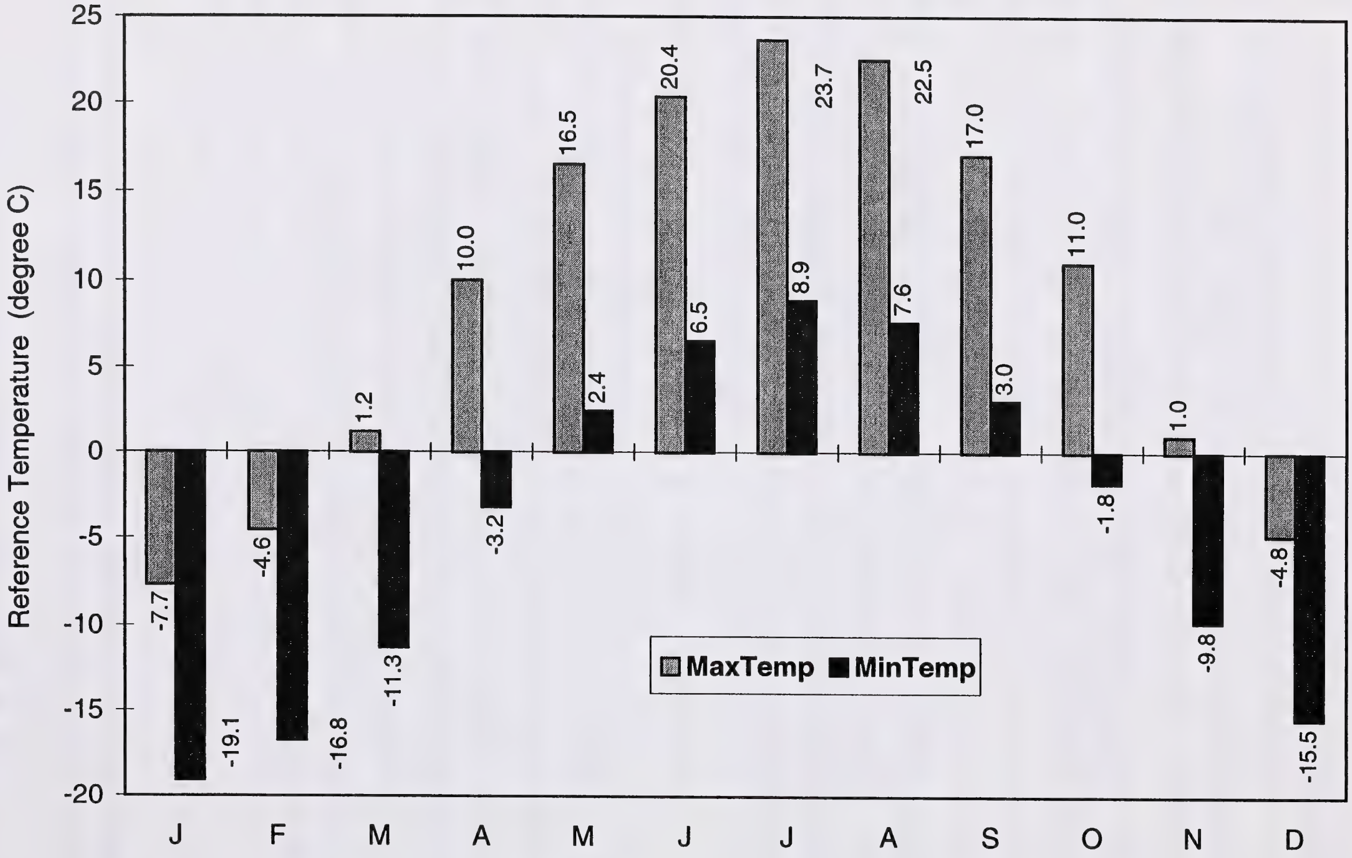

Figure A. Reference period (1961-1990) averages of Alberta temperature.

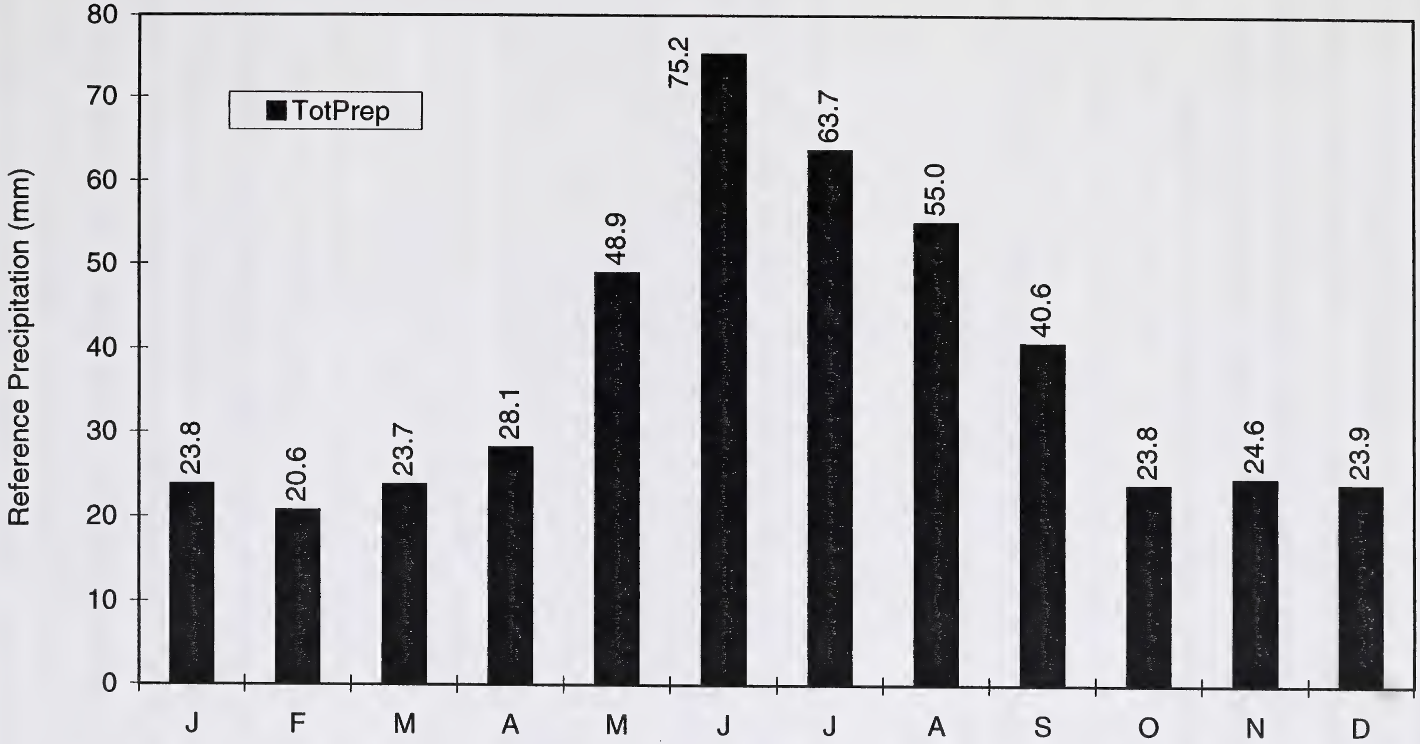

Figure B. Reference period (1961-1990) averages of Alberta precipitation.

a whole. In this study, a uniform average (arithmetic mean) and an optimal average were used. Both these averages can be represented as weighted averages over the available stations. The uniform average is a common measure that is easy to compute and has certain intuitive appeal. The optimal average, however, is more involved computationally, but with weights reflecting the variability and correlation structure of the data field. Specifically, the weights were computed using the variance-covariance matrix of the climate variable observed over the stations.

The Uniform Average

The common arithmetic mean of a climate variable over the number of stations is a weighted average with uniform weights. In the present study, this is represented by

$$\overline{T} = \sum_{i=1}^{N} w_i T_i \qquad \textbf{(1)}$$

where N is the number of stations, w_i is the weight and T_i is the observation at the i^{th} station. The values of the weights are uniform for all stations and are equal to $1/N$. If all stations report data for the month, then $N = 38$. In the case of missing data, the averages over the remaining stations were used as estimates. The uniform average is optimal when the climate variables measured at the stations represent spatial white noise. This means the stations are not correlated, and have approximately the same variance. However, when such conditions do not exist, as in the case of climate stations, the uniform average may be affected by significant biases.

The Optimal Average

The optimal average is also represented by Equation (1) above, but with weights computed using the variance-covariance structure of the climate variable from the stations. The mathematical details are described in Appendix B and the cited references therein. See also Shen et al, (1994) and Shen and Wang (1997) for climatological applications. A desirable feature of the optimal average is that the weights are obtained by minimizing the mean squared error between the true spatial average and the estimated average, with consideration of the variability (variance) and the

correlation (covariance) of the observations. In essence, a station with larger variance and higher correlation with other stations is weighted less. The uncertainty of the method is mainly from the estimates of the covariance structure. However, it has been shown that the estimate of covariance is usually more robust than the estimate of the average of the observation field. (Kim and North, 1993) Also, the optimal method allows careful tuning and testing to optimize the estimate. The most important tuning parameter is the length scale, which is based on the *e*-fold criterion for decorrelation. This length scale represents the distance at which the spatial correlation between pairs of stations have decreased to approximately $1/e$ and must be computed for each climate variable involved. For Alberta, the length scale for temperature is approximately 700 Km and that for precipitation is approximately 220 Km.

RESULTS

For the maximum and minimum temperatures, the monthly averages were first computed for each station. Then the anomalies were computed as departures of the monthly averages from the respective reference period averages for the station. Both uniform and optimal averaging were applied over the stations to obtain the Alberta average for each month. The annual values were then computed as the arithmetic means over the twelve monthly values. For the present study, the focus is on the annual average and the months of January and July for winter and summer conditions respectively. Similar calculations were performed for the total precipitation.

The resulting time sequences contained considerable noise. An eleven-year running mean was used to help reveal the underlying variations by smoothing the data sequences. Other kinds of smoothing techniques could also be used, such as the 21-point binomial filter used in IPCC (1996), but the eleven-year running mean provided the necessary level of smoothing and has certain convenience in its interpretation. For example, each value of the running mean approximates closely the decadal mean centred over the particular point in time. Both the uniform average and optimal average sequences were smoothed by the running mean and the results are shown in Figures C to G, and Figures 4 to 7 in Appendix A.

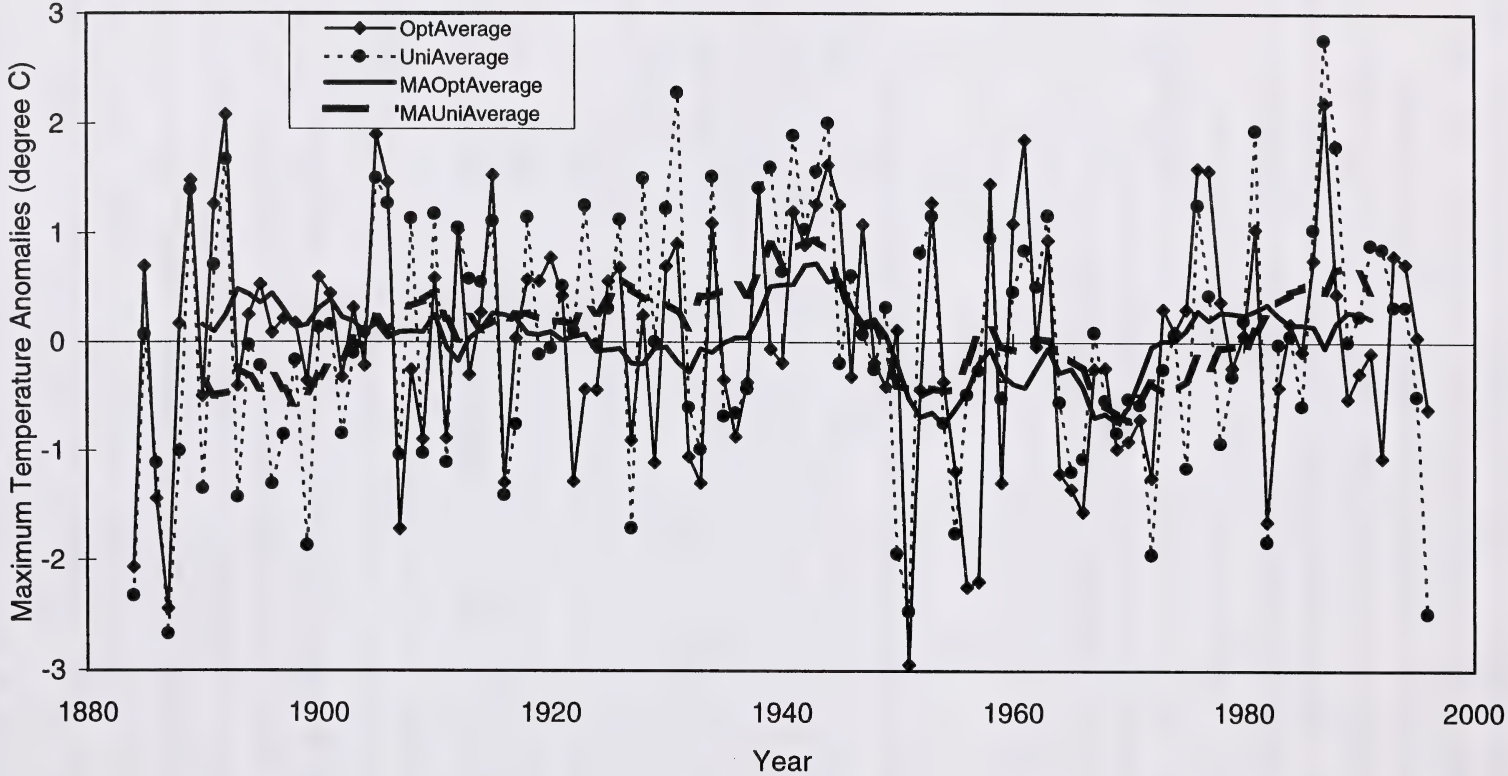

Figure C. Uniform and optimal averages of annual maximum temperature anomalies smoothed with the 11-year running mean.

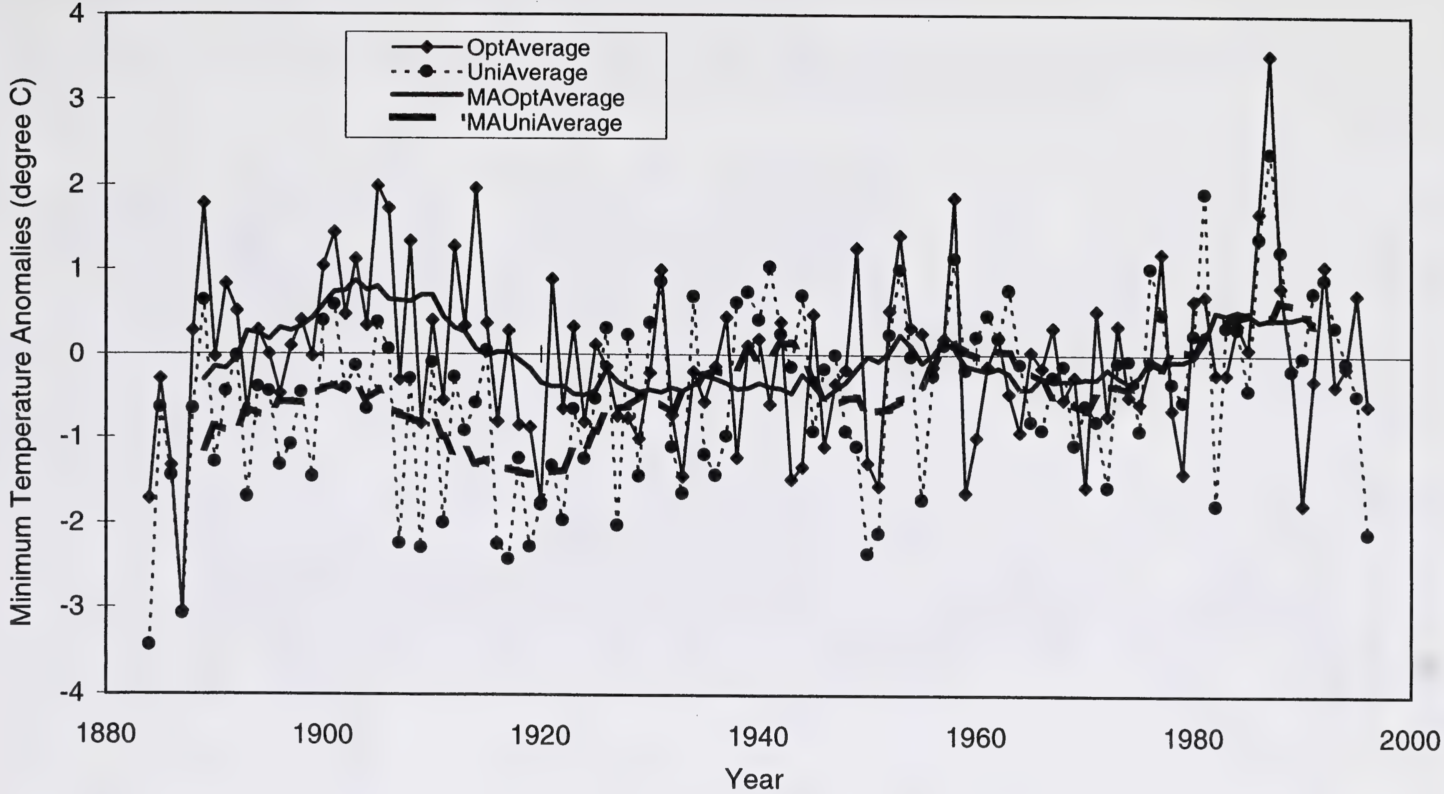

Figure D. Uniform and optimal averages of
annual minimum temperature anomalies smoothed with the 11-year running mean.

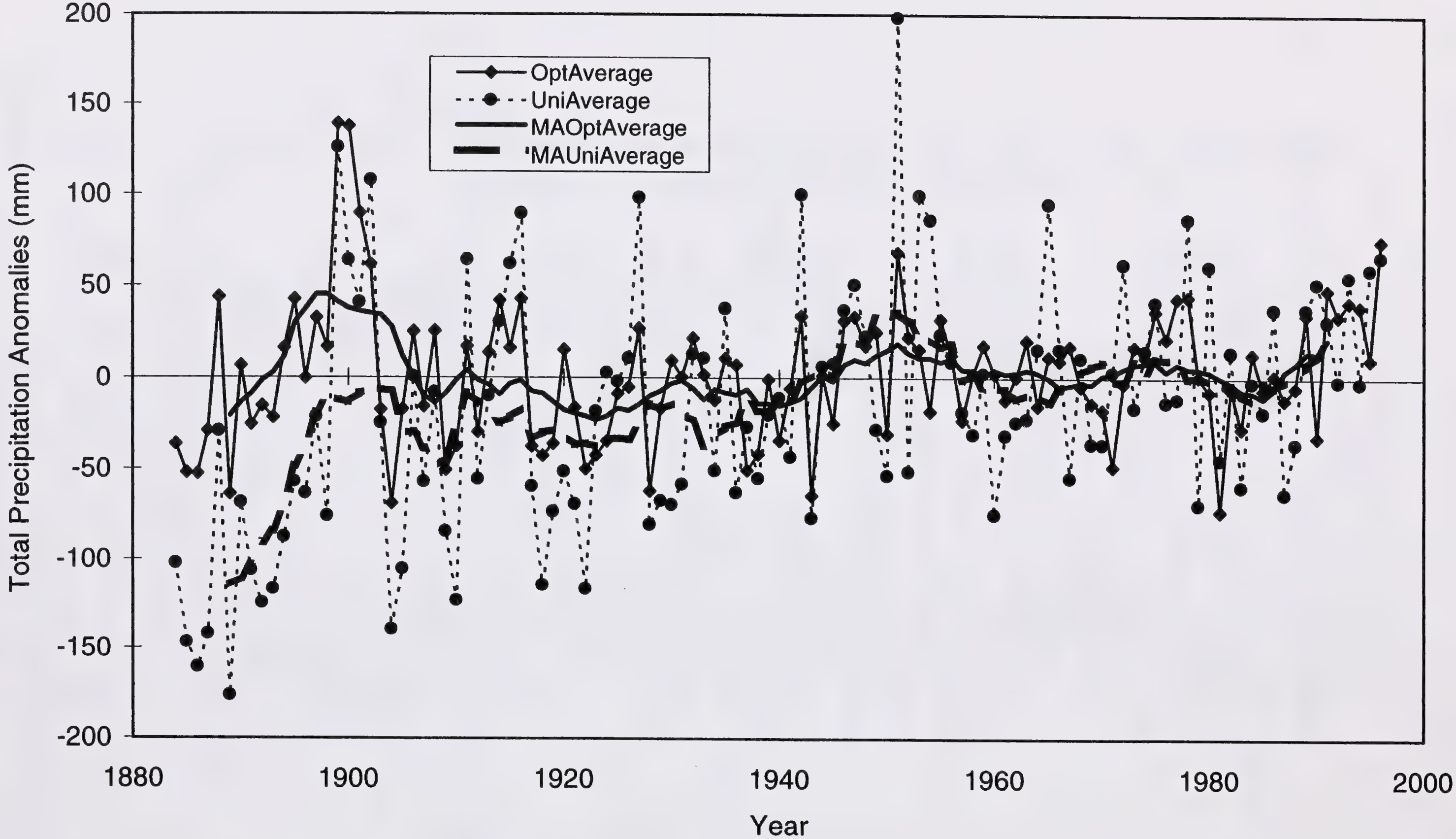

Figure E. Uniform and optimal averages of annual total precipitation anomalies smoothed with the 11-year running mean.

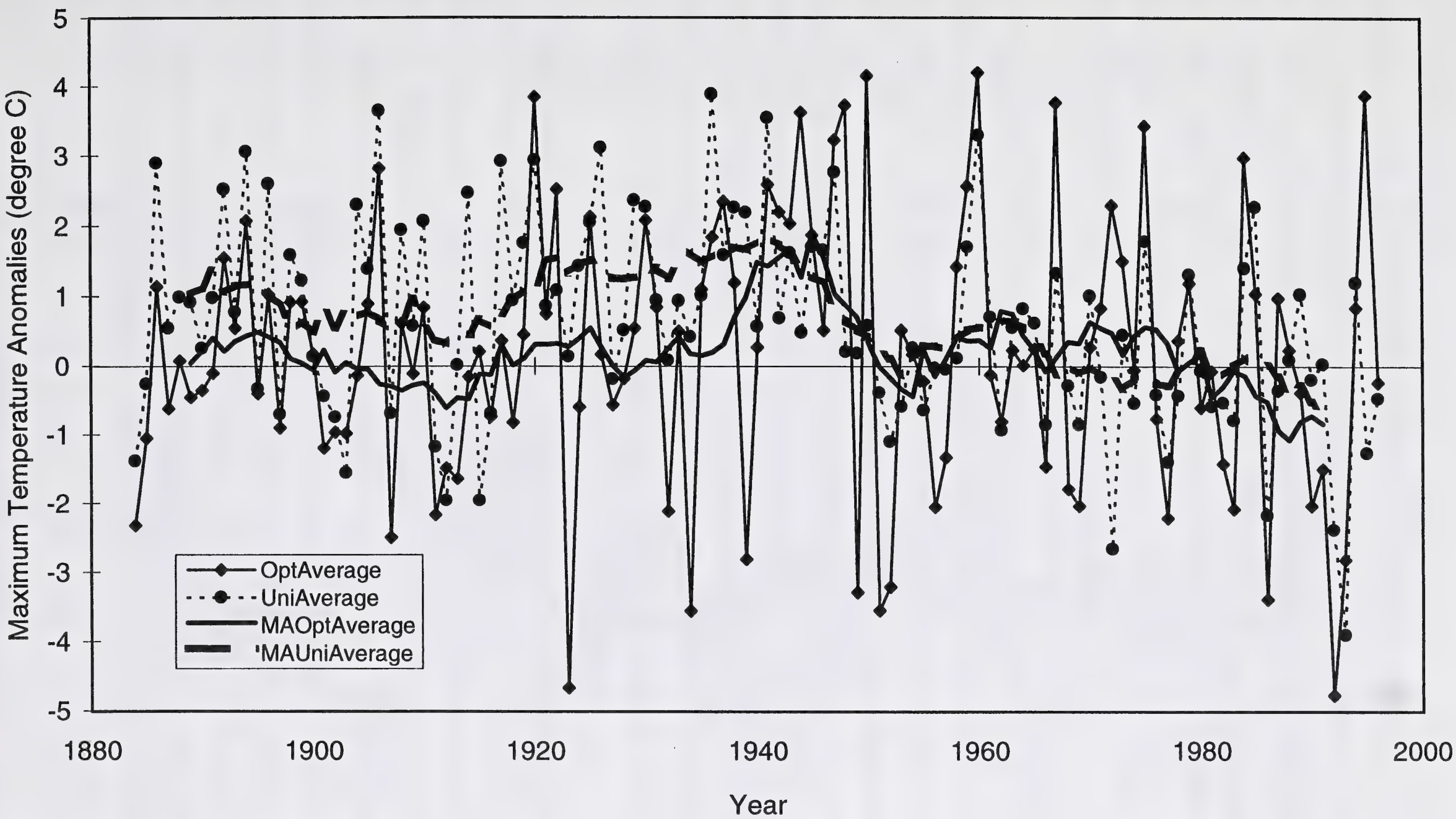

Figure F. Uniform and optimal averages of
July maximum temperature anomalies smoothed with the 11-year running mean.

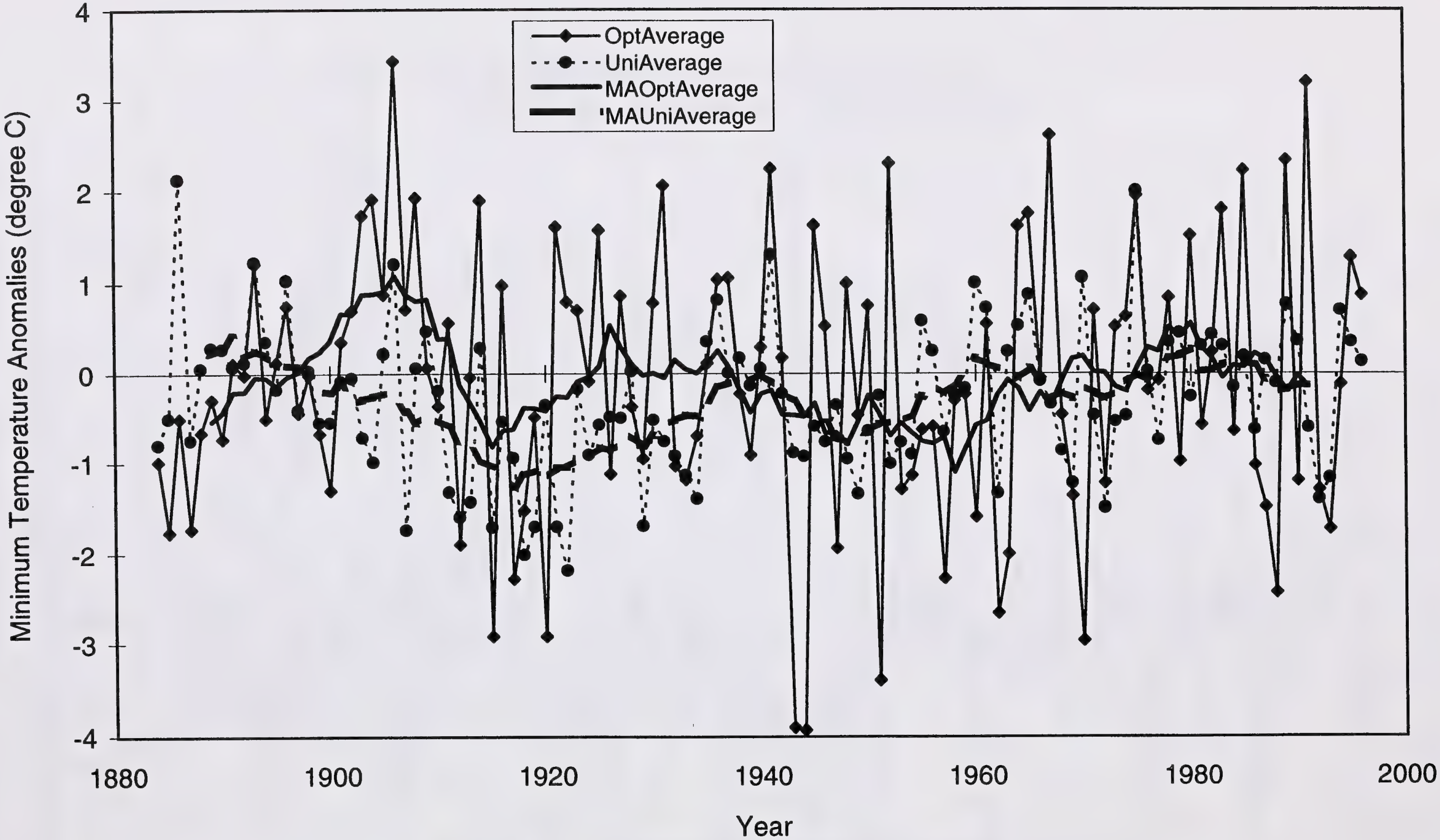

Figure G. Uniform and optimal averages of July minimum temperature anomalies smoothed with the 11-year running mean.

Figure C shows the variations of the annual averages of monthly maximum temperature anomalies over Alberta. Note that the data shown are anomalies and the zero line represents the average over the reference period. Both uniform average and optimal average show a peak around 1940 and 1980 and a low period around 1950s and 1960s. The hottest year for the study period is 1986. However, one observes no general increase of annual average maximum temperature over the data period. An interesting feature is the increases shown by the uniform averages (during the period 1920 to 1940 and around 1900 and 1980) disappear when averaging is done with optimal weights.

A more significant difference exists with the annual averages of monthly minimum temperature anomalies. Figure D shows that for the minimum temperature, the uniform averages before 1930 are much lower than the optimal averages. The result is that a much more significant warming over a longer period is observed using averages with uniform weights than those with optimal weights. With optimal averages, an increasing trend appears to begin around 1920 and continue through 1990s but is less significant. In either case, it is clear that the minimum temperature over Alberta has increased since 1920. The increase represented by the decadal means (centred at 1925 and 1991) is of the order of 0.8 degree C for the period 1920 to 1996, based on the optimal averaging method. The main warming periods are between 1920 and 1950, and 1970 to 1990.

The annual average total precipitation (Figure E) has peaks around 1900 and 1950. Generally, precipitation data are much more variable. The trend estimates are therefore less reliable than in the temperature case. However, there appears to be a slow upward trend observable from the optimal averages, starting around 1920 and lasting till 1990s. The estimate of increase in terms of decadal means is 38.1 mm using the optimal averaging method. Annual average total precipitation is now 21.3 mm more than the average over the reference period. This still does not exceed the peak observed around 1900. Here again, the uniform averages show a more significant increase, mainly because of the lower estimates in the early years of the data period. There were very few stations in the early years and this contributes to lower reliability of the estimates obtained from both methods. However, the optimal averaging method appears to be more robust to such effects.

For the average July maximum temperature over the province, there is no observable upward trend over the data period from the optimal averaging method. (See Figure F.) In fact, there has been a steady decrease in July maximum temperature since the 1940s when a peak occurred. This decrease is more significant from the uniform averages, which register approximately one degree higher in the period before 1940. No obvious trend is observed in the January maximum temperature (Figure 4).

The average minimum temperature in July over the province (Figure G) also peaks in the 1900s based on the optimal averages and there is no clear rising trend unless one considers the period after 1950. An interesting feature in Figure G is that the uniform averages show a steady increase of minimum temperature from the 1910s. Since there is no obvious trend in January minimum temperature (Figure 5) consistent with the period 1920 to 1990 it appears that the aforementioned increasing trend in annual minimum temperature is not reflected in the data of January or July. It would be useful to further examine the month by month minimum temperature variation and identify those months that have a significant increase in minimum temperature.

The optimal average of total precipitation for January (Figure 6) does not show any observable trend. The variation over the data period does not differ much from the average over the reference period. The uniform average results are more variable and show an increasing trend till the 1970s and decreasing trend since then. There is greater agreement between the two averaging methods in the case of July total precipitation, although the optimal averages still demonstrate less significant changes. There is a discernible small increase in July precipitation from about 1920 to 1990s (Figure H).

DISCUSSION

The optimal average provides a more conservative estimate of climatic trends than the uniform average. It also has the theoretical basis for a better integral measure of climate variables over a region. It was demonstrated in the present study that using uniform averaging to obtain Alberta climatic trends results in inflated estimates. This is in contrast with climatic averages over larger

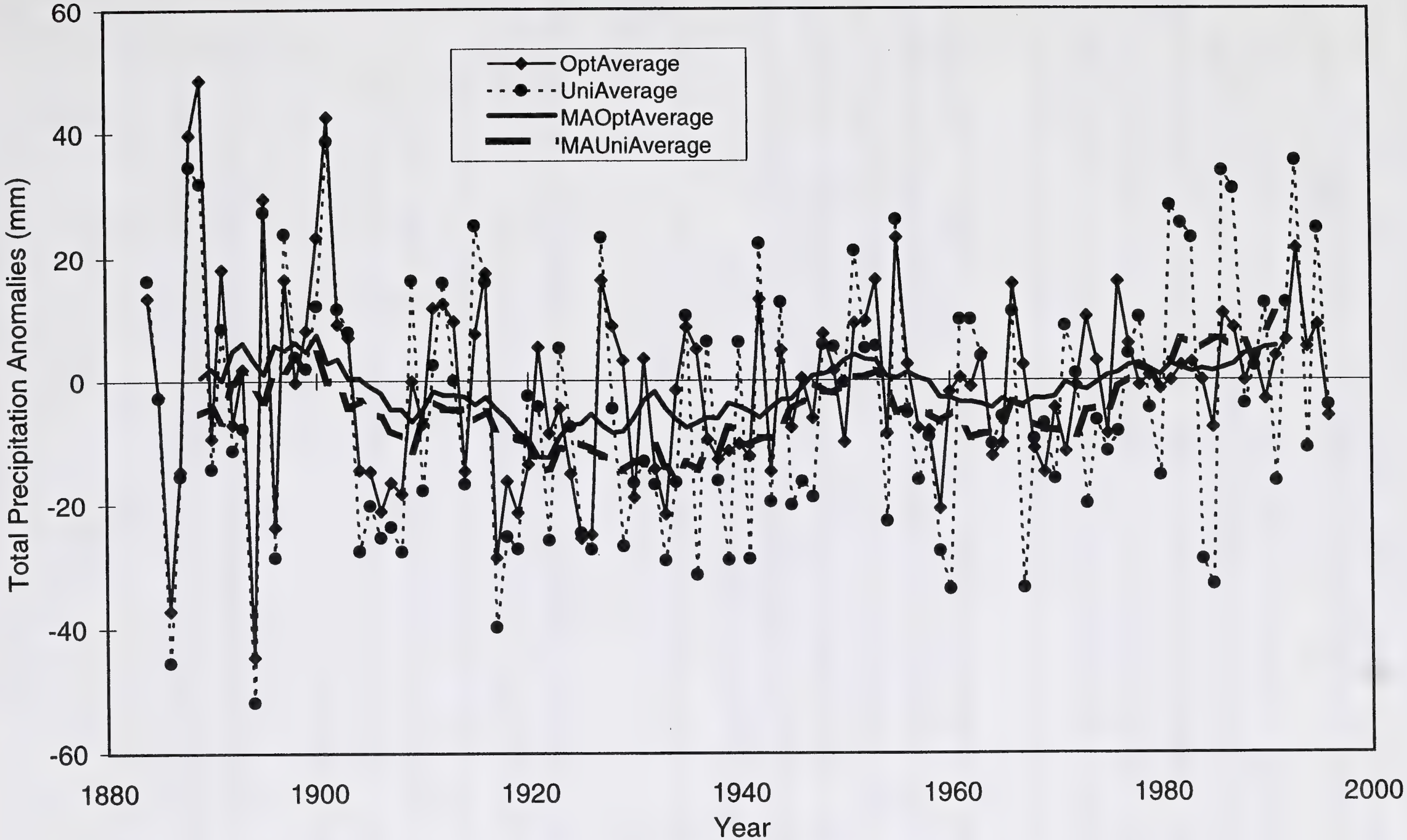

Figure H. Uniform and optimal averages of
July total precipitation anomalies smoothed with the 11-year running mean.

areas which have shown insensitivity to spatial averaging techniques (Parker, 1994). The focus is therefore on the optimal averages in the present description of Alberta climatic trends.

No attempts were made to fit a straight line to the data for trend estimate in this study, as this assumes linearity, which oversimplifies the actual change. Instead, it was decided to use the difference between smoothed end point values of a period of general trend as an estimate for the magnitude of change, and use smoothing filters to show the pattern of variation (IPCC, 1990, 1996). However, it would be useful to estimate the linear trend and perform significance tests in a future study to provide an alternative estimate and confirm the results in probabilistic terms.

It would also be useful to examine the minimum temperature trend from other months in future studies to identify those with significant warming. Climate models estimate greater warming in northern latitudes and that late fall and winter months would see the largest warming effect (IPCC, 1996, p.305). This is not supported by at least the January temperature observations shown in the present analysis. The question remains whether this difference from model estimates is a widespread feature or a regional exception.

CONCLUSIONS

Historical variations in temperature and precipitation in Alberta were assessed using both spatial and temporal smoothing techniques. Optimal averages computed over Alberta were smoothed using an eleven-year running mean in an effort to reveal long-term trends in these climate variables. The present discussion is limited to observable trends since around 1920, in consideration of the number of available stations and the length of period involved. The following features are observed:

- The annual average maximum temperature over Alberta has peaks around 1940 and 1980. However, there is no obvious upward trend in maximum temperature over Alberta.

- The annual average minimum temperature over Alberta has increased since about 1920. The increase is about 0.8 degree, based on estimates using the optimal averaging method. The main warming periods are between 1920 and 1950, and 1970 to 1990.

- There is no observable long-term increase in January or July, maximum or minimum temperatures over Alberta since 1920. This is inconsistent with the increase in annual minimum temperature observed and indicates significant month-to-month variations. It is worthwhile to examine the minimum temperature trend for each month and identify the months with significant warming.

- The annual total precipitation over Alberta shows a slow upward trend from 1920s to the present. The increase was estimated to be around 38.1 mm. There is also an increase in July total precipitation over Alberta since 1920, but no clear trend is identified in the January total precipitation. The July increase is approximately 15mm. However, because of the greater variability of precipitation data, the accuracy of these estimates needs to be further assessed.

- It would be useful to further analyze these trends and assess their significance using statistical tests.

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APPENDIX A: TABLES AND FIGURES

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Table 1. Selected long-term climate stations in Alberta. Latitudes and longitudes are in degree.minute format.

StnID	StnNo	Station Name	Region	Latitude	Longitude	Elevation (m)	Start Year
1	3050520	BANFF	ROCK	51.11	115.34	1397	1887
2	3050600	BEAVER MINES	ROCK	49.28	114.10	1286	1912
3	3070560	BEAVERLODGE CDA	PRB	55.12	119.24	745	1915
4	3030856	BROOKS AHRC	SSRB	50.33	111.51	758	1915
5	3031000	CALDWELL	SSRB	49.09	113.38	1286	1932
6	3031093	CALGARY INT'L A	SSRB	51.07	114.01	1077	1881
7	3011120	CALMAR	NSRB	53.17	113.51	720	1914
8	3061200	CAMPSIE	ARB	54.08	114.41	671	1910
9	3031320	CARDSTON	SSRB	49.12	113.19	1193	1918
10	3031400	CARWAY	SSRB	49.00	113.22	1359	1914
11	3012195	EDMONTON	NSRB	53.33	113.30	658	1880
12	3062240	EDSON	ARB	53.35	116.25	923	1914
13	3062440	ENTRANCE	ARB	53.23	117.41	991	1917
14	3072520	FAIRVIEW	PRB	56.04	118.23	670	1931
15	3032800	GLEICHEN	SSRB	50.52	113.30	905	1885
16	3033240	HIGH RIVER	SSRB	50.30	114.09	1219	1883
17	3053520	JASPER	ROCK	52.53	118.04	1061	1926
18	3053600	KANANASKIS	ROCK	51.02	115.02	1391	1939
19	3023720	LACOMBE CDA	RDRB	52.28	113.45	847	1907
20	3053760	LAKE LOUISE	ROCK	51.25	116.10	1524	1915
21	3033890	LETHBRIDGE CDA	SSRB	49.42	112.47	899	1908
22	3044200	MANYBERRIES CDA	MRB	49.07	110.28	934	1928
23	3034480	MEDICINE HAT A	SSRB	50.01	110.43	717	1883
24	3024920	OLDS	RDRB	51.47	114.06	1040	1914
25	3055120	PEKISKO	ROCK	50.22	114.25	1439	1905
26	3015400	RANFURLY	NSRB	53.27	111.39	686	1905
27	3025480	RED DEER A	RDRB	52.11	113.54	905	1938
28	3015960	SION	NSRB	53.53	114.04	701	1908
29	3033880	LETHBRIDGE A	SSRB	49.38	112.48	929	1938
30	3011890	CORONATION	NSRB	52.07	111.27	789	1912
31	3072657	FORT CHIPEWYAN	PRB	58.43	111.09	219	1883
32	3062693	FORT MCMURRAY A	ARB	56.39	111.13	253	1945
33	3072720	FORT VERMILION CDA	PRB	58.23	116.02	279	1908
34	3072920	GRANDE PRAIRIE A	PRB	55.11	118.53	666	1942
35	3073146	HIGH LEVEL A	PRB	58.37	117.10	324	1971
36	3075040	PEACE RIVER A	PRB	56.14	117.26	326	1944
37	3015530	ROCKY MOUNTAIN HOUSE	NSRB	52.23	114.55	969	1915
38	3066000	SLAVE LAKE	ARB	55.17	114.46	585	1922

Table 2. Monthly average of daily maximum temperature (degree C) over the reference period

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	-5.28	0.11	3.82	8.95	14.18	18.73	22.15	21.58	16.10	10.13	0.52	-5.29
2	BEAVER MINES	-2.61	0.67	3.58	9.44	14.90	19.24	22.88	22.39	16.90	11.78	3.13	-1.67
3	BEAVERLO. CDA	-8.96	-5.17	-0.15	8.66	15.80	19.55	21.64	20.85	15.34	9.60	-1.88	-7.31
4	BROOKS AHRC	-6.89	-2.44	3.11	12.21	18.70	23.01	25.85	25.24	18.92	13.58	2.14	-4.57
5	CALDWELL	-2.40	1.17	3.66	9.15	15.17	19.47	23.53	22.70	17.11	12.18	3.59	-0.14
6	CALGARY INT'L A	-3.59	-0.46	3.27	10.59	16.38	20.63	23.20	22.71	17.39	12.61	2.95	-2.33
7	CALMAR	-7.81	-3.97	1.13	10.64	18.09	21.60	23.04	22.35	17.14	11.95	0.24	-6.24
8	CAMPSIE	-9.05	-4.20	1.29	10.13	17.40	20.96	22.70	21.57	16.05	10.79	-0.99	-7.60
9	CARDSTON	-0.31	1.96	4.77	10.88	16.49	21.08	24.91	24.12	18.40	13.95	5.15	0.07
10	CARWAY	-1.88	1.05	3.34	9.14	14.52	18.95	22.97	22.71	17.16	12.20	3.92	-0.82
11	EDMONTON	-8.15	-4.23	1.06	10.49	17.55	21.28	23.01	22.13	16.59	11.26	-0.13	-6.40
12	EDSON	-6.38	-1.92	2.77	10.25	16.03	19.71	21.88	20.96	15.89	10.74	0.03	-5.24
13	ENTRANCE	-5.09	-0.86	4.05	10.32	15.87	20.03	22.10	21.48	16.13	11.09	1.49	-2.47
14	FAIRVIEW	-11.34	-6.69	-1.28	8.57	16.08	20.11	21.83	20.75	15.08	8.77	-3.14	-9.24
15	GLEICHEN	-6.14	-2.27	3.05	11.77	18.06	22.34	24.75	24.44	18.48	13.23	2.15	-4.31
16	HIGH RIVER	-2.94	0.15	3.44	10.12	15.67	20.07	23.11	22.66	17.25	12.53	3.80	-1.72
17	JASPER	-6.04	-0.34	4.17	10.11	15.43	19.53	22.21	21.73	16.22	10.29	0.47	-5.48
18	KANANASKIS	-2.73	0.79	3.62	8.70	13.69	18.41	21.59	20.89	16.05	11.08	2.78	-1.68
19	LACOMBE CDA	-7.97	-3.96	1.16	10.19	17.07	20.71	22.59	22.01	16.80	11.81	0.45	-6.29
20	LAKE LOUISE	-7.53	-2.02	2.24	7.07	12.77	17.17	20.39	20.08	14.29	7.92	-1.67	-7.62
21	LETHBRIDGE CDA	-2.76	1.27	5.32	12.21	17.96	22.38	25.58	24.95	19.01	14.19	4.46	-1.12
22	MANYBER. CDA	-5.80	-2.31	3.19	11.51	17.98	23.00	26.88	26.34	19.46	13.44	2.98	-3.77
23	MEDICINE HAT A	-5.10	-1.12	4.70	12.98	19.29	24.03	27.30	26.84	20.30	14.42	3.76	-3.02
24	OLDS	-5.81	-2.36	1.42	9.49	15.88	19.84	21.98	21.61	16.47	11.74	1.53	-4.04
25	PEKISKO	-2.77	0.13	2.48	8.01	13.64	18.01	21.24	20.67	15.70	11.04	2.82	-1.59
26	RANFURLY	-10.67	-6.60	-1.09	9.61	17.57	21.13	22.64	22.06	15.92	10.34	-1.67	-8.68
27	RED DEER A	-7.74	-3.88	1.23	10.16	16.88	20.65	22.65	22.19	16.99	11.87	0.48	-6.11
28	SION	-8.07	-4.37	0.89	9.73	17.18	20.77	22.59	21.59	16.18	10.76	-0.75	-6.70
29	LETHBRIDGE A	-2.61	1.09	5.26	12.20	18.02	22.60	25.93	25.33	19.61	14.32	4.55	-0.93
30	CORONATION	-9.63	-6.16	-0.58	9.84	17.33	21.53	23.86	23.29	17.06	11.38	-0.31	-7.55
31	FORT CHIPEWYAN	-19.22	-13.99	-6.19	5.18	14.21	20.10	22.39	20.65	13.21	5.56	-7.32	-15.17
32	FORT MCMUR. A	-14.54	-8.58	-1.10	9.30	17.14	21.46	23.21	21.78	15.05	8.37	-4.52	-12.56
33	FORT VERMI. CDA	-18.16	-11.98	-3.68	7.84	16.68	21.50	23.07	21.33	14.61	6.73	-6.84	-15.66
34	GRANDE PRA. A	-10.03	-6.13	-0.30	9.26	16.61	20.30	22.20	21.42	15.96	10.10	-2.08	-8.35
35	HIGH LEVEL A	-15.81	-11.35	-3.14	8.66	16.94	21.06	22.92	20.89	14.84	6.00	-8.12	-14.68
36	PEACE RIVER A	-12.18	-7.62	-1.14	9.13	16.80	20.67	22.38	21.19	15.39	8.90	-3.80	-10.08
37	ROCKY MT HOUSE	-5.55	-1.56	2.43	9.85	15.95	19.76	21.82	21.25	16.36	11.74	1.23	-4.48
38	SLAVE LAKE	-9.49	-6.36	0.53	9.20	16.00	19.54	21.35	20.22	14.59	9.22	-1.96	-8.77
	Average	-7.34	-3.28	1.64	9.78	16.37	20.55	23.06	22.29	16.58	10.99	0.25	-5.78

Table 3. Monthly average of daily minimum temperature (degree C) over the reference period

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	-14.86	-11.31	-7.94	-2.79	1.48	5.40	7.39	6.78	2.65	-1.08	-8.19	-13.77
2	BEAVER MINES	-12.24	-9.30	-6.39	-1.65	2.85	6.54	8.23	7.83	4.16	1.05	-5.77	-10.56
3	BEAVERLO. CDA	-18.14	-14.85	-9.96	-2.31	3.13	7.04	8.91	7.96	3.76	-0.66	-10.21	-16.40
4	BROOKS AHRC	-18.14	-14.04	-8.51	-2.05	4.04	8.80	10.84	9.69	4.23	-0.91	-9.44	-15.98
5	CALDWELL	-12.98	-9.59	-6.68	-1.98	2.76	6.72	9.19	8.41	4.42	0.75	-6.16	-10.35
6	CALGARY INT'L A	-15.70	-12.26	-8.43	-2.42	2.96	7.34	9.47	8.55	3.77	-1.18	-9.01	-14.37
7	CALMAR	-19.14	-15.89	-10.44	-2.32	3.34	7.72	9.57	8.47	3.73	-1.35	-10.25	-17.08
8	CAMPSIE	-21.21	-17.71	-11.68	-3.57	2.37	6.72	8.91	7.68	2.53	-2.52	-11.59	-19.35
9	CARDSTON	-12.84	-10.33	-7.09	-1.49	3.54	7.39	9.60	8.82	4.25	0.40	-6.98	-11.34
10	CARWAY	-13.37	-10.60	-7.49	-2.46	2.06	5.84	7.93	7.72	3.46	-0.27	-7.24	-11.88
11	EDMONTON	-16.96	-13.68	-8.38	-0.73	5.68	9.93	12.04	10.99	5.62	0.57	-8.39	-14.84
12	EDSON	-19.25	-15.82	-10.97	-3.92	1.37	5.50	7.73	6.91	1.94	-3.12	-11.96	-17.69
13	ENTRANCE	-17.47	-15.00	-10.27	-3.99	0.59	4.56	6.40	5.75	1.01	-2.43	-9.97	-13.76
14	FAIRVIEW	-19.38	-15.54	-10.49	-1.77	4.23	8.52	10.52	9.30	4.61	-0.37	-10.67	-17.13
15	GLEICHEN	-17.61	-14.14	-9.01	-2.40	3.32	7.72	9.72	8.99	3.69	-1.65	-9.61	-15.71
16	HIGH RIVER	-15.49	-12.47	-8.81	-3.16	1.66	5.61	7.20	6.67	2.31	-1.67	-8.75	-13.85
17	JASPER	-15.56	-11.60	-7.44	-2.54	2.03	5.99	7.99	7.37	3.22	-0.86	-8.50	-14.16
18	KANANASKIS	-14.37	-11.15	-8.52	-3.43	0.70	4.32	6.36	5.98	2.01	-0.91	-7.60	-12.51
19	LACOMBE CDA	-18.98	-15.72	-10.52	-2.73	3.03	7.29	9.04	7.97	3.12	-2.18	-10.32	-17.06
20	LAKE LOUISE	-21.35	-18.12	-13.99	-6.75	-1.69	2.15	3.62	3.09	-0.81	-5.32	-13.93	-20.36
21	LETHBRIDGE CDA	-14.59	-10.83	-6.98	-1.10	4.29	8.75	10.51	9.71	4.84	0.41	-6.98	-12.40
22	MANYBER. CDA	-17.06	-13.77	-8.30	-1.38	4.55	9.04	11.63	10.95	4.82	-0.94	-9.14	-15.19
23	MEDICINE HAT A	-16.44	-12.67	-7.14	-0.43	5.55	10.05	12.24	11.42	5.60	0.20	-8.11	-14.26
24	OLDS	-16.77	-14.07	-9.37	-2.67	2.77	7.19	9.15	8.06	3.28	-1.68	-9.41	-15.00
25	PEKISKO	-16.33	-13.54	-10.71	-4.97	-0.24	3.32	4.96	4.54	0.61	-2.91	-9.78	-14.93
26	RANFURLY	-20.59	-16.81	-11.34	-2.11	4.14	8.40	10.45	9.25	4.04	-0.88	-10.26	-17.91
27	RED DEER A	-19.37	-16.23	-10.78	-2.92	2.80	7.22	8.93	7.81	2.74	-2.81	-11.16	-17.78
28	SION	-18.39	-15.11	-10.19	-2.36	3.63	7.50	9.56	8.86	3.95	-0.75	-9.66	-16.15
29	LETHBRIDGE A	-14.23	-10.83	-6.92	-1.03	4.35	8.98	10.88	10.25	5.26	0.58	-7.13	-12.52
30	CORONATION	-20.14	-16.70	-10.96	-2.55	3.42	8.02	10.22	9.03	3.52	-2.04	-10.93	-17.85
31	FORT CHIPEWYAN	-29.89	-25.85	-19.56	-6.55	2.05	8.09	10.77	9.11	3.58	-2.73	-16.15	-25.03
32	FORT MCMUR. A	-25.25	-21.29	-14.81	-3.78	3.02	7.70	10.01	8.48	3.18	-1.89	-13.53	-22.12
33	FORT VERMI. CDA	-27.28	-22.81	-16.15	-4.16	3.69	8.35	10.73	8.85	3.13	-2.46	-14.40	-24.17
34	GRANDE PRA. A	-20.89	-17.41	-11.61	-2.64	3.60	7.80	9.66	8.40	3.65	-1.44	-11.82	-19.01
35	HIGH LEVEL A	-27.18	-24.88	-17.70	-5.02	2.42	7.30	9.35	7.11	1.58	-4.17	-17.53	-25.60
36	PEACE RIVER A	-22.93	-19.11	-13.33	-3.27	2.99	7.41	9.43	7.97	3.04	-2.24	-13.27	-20.40
37	ROCKY MT HOUSE	-18.17	-14.89	-10.13	-3.26	2.12	6.28	8.34	7.45	2.41	-2.20	-10.68	-16.80
38	SLAVE LAKE	-19.81	-17.92	-11.40	-3.14	2.98	7.68	9.94	8.61	3.40	-1.55	-10.78	-18.23
	Average	-18.43	-15.10	-10.27	-2.84	2.83	7.11	9.14	8.18	3.32	-1.40	-10.14	-16.41

Table 4. Monthly average of total rainfall (mm) over the reference period

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	2.4	1.7	1.6	10.5	42.4	58.4	51.1	51.2	37.7	15.4	6.0	2.8
2	BEAVER MINES	3.8	2.6	3.3	15.1	64.9	81.8	48.0	51.0	50.5	16.9	9.7	5.2
3	BEAVERLO. CDA	0.7	0.5	1.2	7.6	34.0	71.8	67.4	63.5	44.7	14.4	2.6	0.5
4	BROOKS AHRC	0.9	0.6	2.2	16.9	39.2	64.3	36.8	36.5	37.0	10.3	2.5	1.0
5	CALDWELL	0.3	0.3	1.6	15.5	74.5	91.9	49.1	58.6	49.0	8.0	3.2	0.8
6	CALGARY INT'L A	0.2	0.2	1.5	9.2	43.9	76.7	69.9	48.7	42.7	6.4	0.7	0.1
7	CALMAR	2.6	0.9	1.7	10.9	48.0	81.2	100.0	67.7	43.2	13.1	2.6	1.0
8	CAMPSIE	0.7	0.2	1.7	12.4	41.4	84.9	88.1	69.0	36.2	10.1	1.2	0.5
9	CARDSTON	0.2	0.0	1.2	10.9	65.3	77.4	46.4	54.3	49.9	11.4	1.4	0.1
10	CARWAY	0.5	0.1	0.8	7.8	56.9	74.4	41.2	44.6	32.1	5.7	1.1	0.5
11	EDMONTON	2.0	0.8	2.0	9.9	40.5	79.9	94.3	67.1	39.9	10.0	2.2	0.9
12	EDSON	1.5	0.6	2.8	9.6	52.4	99.5	112.5	81.1	54.9	13.1	2.4	0.9
13	ENTRANCE	1.0	0.4	1.0	10.0	57.4	72.4	91.6	63.4	45.4	12.7	1.8	0.5
14	FAIRVIEW	0.8	0.4	1.0	9.6	40.5	71.7	75.5	54.0	34.5	17.4	4.4	1.2
15	GLEICHEN	0.8	0.2	1.5	12.8	44.0	62.7	47.7	37.7	40.1	8.4	1.8	0.4
16	HIGH RIVER	0.1	0.1	0.8	13.8	52.7	86.4	58.7	55.5	41.5	7.5	0.6	0.3
17	JASPER	4.6	2.7	4.2	12.1	27.8	49.6	56.2	50.5	36.0	24.1	9.2	4.4
18	KANANASKIS	1.2	0.6	1.0	12.9	57.6	83.8	63.9	67.7	53.4	11.8	3.5	2.7
19	LACOMBE CDA	0.9	1.0	1.0	8.1	45.5	74.9	86.0	65.2	45.7	10.5	1.5	0.3
20	LAKE LOUISE	0.6	0.9	1.7	5.5	34.4	54.5	61.2	54.0	41.1	13.6	1.2	0.1
21	LETHBRIDGE CDA	0.5	0.2	2.5	14.6	46.4	64.4	39.8	44.7	37.2	8.5	1.2	0.5
22	MANYBER. CDA	0.2	0.3	2.3	13.2	45.7	57.0	31.9	34.2	30.1	7.4	1.1	0.6
23	MEDICINE HAT A	0.5	0.2	2.9	12.6	40.0	56.4	40.9	30.6	34.2	8.7	2.3	0.8
24	OLDS	0.5	0.1	1.6	10.8	49.8	85.6	85.4	59.5	50.1	10.1	0.6	0.0
25	PEKISKO	0.7	0.3	0.6	14.3	58.6	99.3	62.6	70.3	46.8	7.1	1.9	0.3
26	RANFURLY	1.1	0.5	1.1	6.4	38.6	74.6	79.2	61.5	37.3	7.9	2.0	0.7
27	RED DEER A	1.1	0.6	1.4	9.3	45.2	85.4	88.0	64.8	50.4	11.2	1.2	0.3
28	SION	1.9	0.4	2.2	10.5	39.9	87.5	90.1	73.7	42.1	13.4	2.2	0.8
29	LETHBRIDGE A	0.2	0.2	2.1	14.6	46.8	66.1	45.3	42.9	36.9	6.4	1.0	0.4
30	CORONATION	0.7	0.3	1.3	7.2	35.4	62.7	72.2	48.8	35.7	8.4	1.9	0.5
31	FORT CHIPEWYAN	0.3	0.2	0.1	4.7	24.5	45.9	64.4	49.3	40.5	18.9	0.7	0.1
32	FORT MCMUR. A	0.6	0.8	0.9	8.0	37.2	63.9	79.1	71.7	48.1	20.0	2.9	1.1
33	FORT VERMI. CDA	0.9	0.7	0.8	7.6	32.0	50.0	65.2	54.2	33.5	16.9	1.3	0.9
34	GRANDE PRA. A	1.7	0.8	1.0	9.3	32.5	74.2	67.9	61.2	39.4	14.7	5.0	1.0
35	HIGH LEVEL A	0.3	0.2	0.3	8.4	35.0	65.0	61.0	56.1	32.8	13.4	0.7	0.5
36	PEACE RIVER A	0.5	0.4	0.3	7.6	28.3	63.4	61.7	50.8	38.2	14.1	3.5	0.7
37	ROCKY MT HOUSE	1.1	0.2	0.9	8.2	52.8	92.3	106.5	71.6	54.8	12.7	1.2	0.2
38	SLAVE LAKE	0.7	0.7	1.5	12.3	36.8	81.3	92.6	66.9	46.1	19.3	3.1	2.3
	Average	1.0	0.6	1.5	10.6	44.4	73.0	67.9	56.7	41.8	12.1	2.5	0.9

Table 5. Monthly average of total snowfall (mm water equivalent) over the reference period

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	38.2	30.0	27.0	26.3	17.1	1.7	0.0	0.1	7.0	18.9	33.6	44.0
2	BEAVER MINES	42.3	32.9	39.8	45.7	10.9	0.3	0.0	0.0	7.7	17.4	33.8	38.6
3	BEAVERLO. CDA	40.1	26.1	26.0	13.2	3.4	0.0	0.0	1.3	2.5	8.9	30.9	34.8
4	BROOKS AHRC	18.6	12.2	15.5	9.8	1.0	0.0	0.0	0.0	0.5	5.1	13.5	19.4
5	CALDWELL	47.8	38.0	54.1	47.6	12.8	1.1	0.0	0.0	14.7	21.9	39.1	49.0
6	CALGARY INT'L A	18.0	14.9	18.7	20.4	10.2	0.3	0.0	0.0	6.4	11.5	16.0	19.0
7	CALMAR	23.2	18.1	17.2	11.2	2.3	0.0	0.0	0.0	1.2	8.7	17.5	21.7
8	CAMPSIE	20.4	19.0	16.2	7.6	2.0	0.7	0.0	0.0	1.1	7.3	16.4	22.7
9	CARDSTON	34.5	24.3	38.4	35.7	9.8	0.6	0.0	0.0	5.6	14.2	30.7	35.5
10	CARWAY	30.1	28.3	40.4	33.6	13.6	1.8	0.0	0.0	13.3	14.0	29.9	32.1
11	EDMONTON	25.6	19.6	17.7	12.8	2.8	0.0	0.0	0.0	1.9	7.4	16.3	25.5
12	EDSON	36.6	26.8	28.7	18.0	7.9	0.0	0.0	0.1	6.0	10.1	23.1	28.4
13	ENTRANCE	31.1	21.8	21.9	13.1	2.4	0.0	0.0	0.0	3.3	9.7	21.1	21.1
14	FAIRVIEW	32.7	26.0	22.8	12.4	3.1	0.0	0.0	0.4	2.3	10.2	25.4	29.4
15	GLEICHEN	15.0	10.5	14.9	13.5	3.8	0.0	0.0	0.0	1.6	4.9	14.1	15.7
16	HIGH RIVER	22.8	22.5	25.7	27.1	7.6	0.3	0.0	0.0	5.5	12.4	18.1	25.0
17	JASPER	34.7	19.3	14.7	10.4	0.9	0.3	0.0	0.1	1.0	7.7	24.7	30.2
18	KANANASKIS	31.8	30.3	43.1	51.1	22.9	1.2	0.0	0.1	12.2	27.6	26.8	31.6
19	LACOMBE CDA	19.7	15.6	15.3	12.7	1.7	0.0	0.0	0.0	1.7	6.6	14.3	19.0
20	LAKE LOUISE	62.7	40.0	32.8	22.3	7.4	0.2	0.0	0.0	3.4	24.4	60.6	75.5
21	LETHBRIDGE CDA	27.2	16.5	26.0	21.9	1.5	0.2	0.0	0.0	5.5	7.6	18.0	25.8
22	MANYBER. CDA	24.3	18.0	21.2	17.8	2.6	0.1	0.0	0.0	1.2	6.3	14.0	22.5
23	MEDICINE HAT A	20.9	12.5	15.0	14.3	2.3	0.0	0.0	0.0	2.1	7.1	14.8	19.3
24	OLDS	21.1	14.8	19.2	15.7	4.9	0.3	0.0	0.0	3.8	8.4	18.8	22.1
25	PEKISKO	36.9	33.4	49.8	57.3	25.6	1.6	0.0	0.0	16.9	28.7	32.3	37.7
26	RANFURLY	20.0	14.5	16.9	12.2	2.6	0.0	0.0	0.0	1.9	7.8	13.7	21.7
27	RED DEER A	22.4	16.8	17.3	14.4	4.2	0.1	0.0	0.0	4.0	9.5	15.5	21.0
28	SION	25.2	21.1	18.5	10.3	3.8	0.0	0.0	0.0	2.2	8.3	19.6	26.2
29	LETHBRIDGE A	26.1	16.1	28.2	24.4	4.9	0.2	0.0	0.0	7.8	9.6	18.2	24.5
30	CORONATION	24.9	19.9	23.1	15.5	3.9	0.0	0.0	0.0	2.8	7.4	17.1	25.2
31	FORT CHIPEWYAN	21.1	16.2	18.4	15.8	3.7	0.1	0.0	0.0	1.4	14.7	28.6	23.2
32	FORT MCMUR. A	27.2	21.3	23.2	15.8	3.6	0.0	0.0	0.0	3.3	14.1	33.1	30.5
33	FORT VERMI. CDA	21.0	17.5	20.7	11.8	2.3	0.0	0.0	0.0	0.7	10.8	20.9	20.2
34	GRANDE PRA. A	39.2	24.9	22.5	11.9	3.1	0.0	0.0	0.7	3.1	7.5	29.6	32.1
35	HIGH LEVEL A	27.7	20.3	22.3	9.5	6.8	0.0	0.0	0.1	1.2	21.7	33.7	26.6
36	PEACE RIVER A	26.4	23.2	17.9	9.4	3.3	0.0	0.0	0.2	2.5	10.8	23.9	23.4
37	ROCKY MT HOUSE	30.0	22.6	28.5	22.9	9.0	0.1	0.0	0.1	5.4	13.1	22.7	27.1
38	SLAVE LAKE	29.8	22.1	23.7	11.3	3.5	0.0	0.0	0.0	3.1	9.5	19.4	28.1
	Average	28.9	21.8	24.8	19.9	6.2	0.3	0.0	0.1	4.4	11.9	23.7	28.3

Table 6. Monthly average of total precipitation (mm) over the reference period

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	40.6	31.6	28.6	36.8	59.5	60.0	51.1	51.3	44.7	34.3	39.6	46.7
2	BEAVER MINES	46.1	35.5	43.1	60.8	75.8	82.1	48.0	51.0	58.2	34.4	43.5	43.8
3	BEAVERLO. CDA	40.7	26.7	27.2	20.8	37.3	71.8	67.4	64.8	47.2	23.4	33.5	35.3
4	BROOKS AHRC	19.5	12.9	17.7	26.7	40.1	64.3	36.8	36.5	37.5	15.4	16.0	20.4
5	CALDWELL	48.1	38.3	55.7	63.1	87.4	93.1	49.1	58.6	63.7	29.9	42.3	49.8
6	CALGARY INT'L A	18.2	15.1	20.2	29.6	54.1	76.9	69.9	48.7	49.2	17.9	16.6	19.1
7	CALMAR	25.8	19.0	18.9	22.1	50.3	81.2	100.0	67.7	44.4	21.8	20.0	22.7
8	CAMPSIE	21.1	19.2	17.9	20.1	43.4	85.6	88.1	69.0	37.3	17.3	17.6	23.2
9	CARDSTON	34.7	24.3	39.6	46.6	75.2	78.0	46.4	54.3	55.5	25.5	32.0	35.6
10	CARWAY	30.5	28.4	41.2	41.5	70.5	76.2	41.2	44.6	45.4	19.8	31.0	32.6
11	EDMONTON	27.7	20.4	19.7	22.6	43.3	79.9	94.3	67.1	41.8	17.4	18.5	26.4
12	EDSON	38.1	27.4	31.5	27.6	60.4	99.5	112.5	81.1	60.8	23.2	25.5	29.3
13	ENTRANCE	32.1	22.2	22.9	23.1	59.7	72.4	91.6	63.4	48.7	22.4	22.9	21.5
14	FAIRVIEW	33.5	26.4	23.8	22.0	43.6	71.7	75.5	54.5	36.8	27.6	29.8	30.7
15	GLEICHEN	15.8	10.7	16.3	26.4	47.8	62.7	47.7	37.7	41.6	13.3	15.9	16.1
16	HIGH RIVER	23.0	22.6	26.5	40.9	60.3	86.8	58.7	55.5	47.1	20.0	18.7	25.2
17	JASPER	39.3	22.0	19.0	22.5	28.7	49.9	56.2	50.7	37.0	31.8	33.9	34.6
18	KANANASKIS	33.0	30.9	44.1	64.0	80.4	85.0	63.9	67.7	65.5	39.4	30.3	34.3
19	LACOMBE CDA	20.6	16.6	16.2	20.8	47.2	74.9	86.0	65.2	47.4	17.1	15.8	19.3
20	LAKE LOUISE	63.3	41.0	34.5	27.8	41.8	54.6	61.2	54.0	44.4	38.1	61.8	75.6
21	LETHBRIDGE CDA	27.6	16.6	28.5	36.4	47.9	64.6	39.8	44.7	42.7	16.2	19.2	26.3
22	MANYBER. CDA	24.5	18.4	23.4	30.9	48.3	57.0	31.9	34.2	31.3	13.7	15.1	23.1
23	MEDICINE HAT A	21.4	12.7	17.8	26.8	42.2	56.4	40.9	30.6	36.3	15.8	17.1	20.1
24	OLDS	21.6	14.8	20.9	26.6	54.7	85.9	85.4	59.5	53.9	18.5	19.4	22.1
25	PEKISKO	37.6	33.7	50.4	71.6	84.3	100.8	62.6	70.3	63.7	35.9	34.2	37.9
26	RANFURLY	21.1	14.9	18.0	18.6	41.2	74.6	79.2	61.5	39.2	15.7	15.6	22.4
27	RED DEER A	23.5	17.4	18.7	23.7	49.3	85.5	88.0	64.8	54.4	20.7	16.6	21.3
28	SION	27.1	21.4	20.7	20.8	43.7	87.5	90.1	73.7	44.4	21.8	21.8	27.0
29	LETHBRIDGE A	26.3	16.3	30.3	39.1	51.7	66.3	45.3	42.9	44.7	16.1	19.2	24.9
30	CORONATION	25.6	20.2	24.4	22.7	39.4	62.7	72.2	48.8	38.5	15.8	19.0	25.7
31	FORT CHIPEWYAN	21.4	16.4	18.5	20.6	28.2	46.0	64.4	49.3	42.0	33.5	29.4	23.3
32	FORT MCMUR. A	27.8	22.1	24.2	23.8	40.8	63.9	79.1	71.8	51.3	34.1	36.0	31.6
33	FORT VERMI. CDA	21.9	18.2	21.5	19.4	34.3	50.0	65.2	54.2	34.2	27.7	22.2	21.1
34	GRANDE PRA. A	40.9	25.7	23.6	21.2	35.5	74.2	67.9	61.9	42.5	22.2	34.6	33.1
35	HIGH LEVEL A	27.9	20.4	22.6	17.9	41.8	65.0	61.0	56.3	34.1	35.1	34.4	27.0
36	PEACE RIVER A	26.9	23.5	18.2	17.0	31.5	63.4	61.7	50.9	40.7	24.9	27.3	24.0
37	ROCKY MT HOUSE	31.1	22.8	29.4	31.0	61.7	92.4	106.5	71.7	60.2	25.8	23.9	27.4
38	SLAVE LAKE	30.5	22.7	25.2	23.6	40.3	81.3	92.6	66.9	49.2	28.8	22.6	30.4
	Average	29.9	22.4	26.3	30.5	50.6	73.3	67.9	56.8	46.2	24.0	26.1	29.2

Table 7. Monthly variance of maximum temperature (degree^2 C)

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	16.78	13.71	7.30	6.16	3.85	3.60	3.23	4.99	7.81	5.68	10.06	10.12
2	BEAVER MINES	23.46	17.02	8.26	7.99	4.60	3.76	4.24	5.44	9.53	6.89	11.93	15.32
3	BEAVERLO. CDA	37.53	24.79	11.07	9.67	3.45	2.36	2.26	4.25	7.06	6.14	22.54	28.44
4	BROOKS AHRC	35.03	30.39	13.53	10.27	5.13	4.26	4.86	6.13	8.15	7.89	21.26	26.33
5	CALDWELL	28.17	18.23	8.81	9.61	6.07	4.07	4.14	5.68	8.18	7.98	11.99	13.18
6	CALGARY INT'L A	31.47	26.15	14.79	11.02	4.53	4.24	4.36	5.35	7.74	7.07	20.46	18.43
7	CALMAR	30.18	23.48	9.92	12.15	3.77	3.11	1.60	3.50	6.76	7.19	20.80	22.90
8	CAMPSIE	30.50	21.99	10.16	9.39	2.89	2.25	2.00	3.75	7.03	6.35	19.71	23.73
9	CARDSTON	27.74	22.54	10.91	8.23	4.90	4.57	4.24	4.43	9.44	10.08	13.08	16.76
10	CARWAY	27.30	14.95	10.01	8.66	4.20	4.16	4.13	5.54	8.59	8.71	12.19	14.25
11	EDMONTON	30.65	23.87	12.53	10.66	3.26	2.70	1.88	3.71	6.02	7.11	18.91	20.62
12	EDSON	28.98	21.00	7.84	8.88	3.32	2.25	2.87	4.77	8.79	7.13	21.31	20.60
13	ENTRANCE	32.16	19.72	7.56	8.68	5.09	3.37	3.37	4.68	8.86	6.05	19.78	24.75
14	FAIRVIEW	34.27	26.18	9.43	9.37	2.67	2.01	1.80	4.08	7.61	5.78	18.59	25.01
15	GLEICHEN	33.54	27.08	16.17	11.77	4.71	4.28	3.76	5.76	8.77	8.77	21.16	21.13
16	HIGH RIVER	35.00	21.66	10.66	10.31	4.93	4.25	5.07	5.83	9.46	8.67	15.54	21.99
17	JASPER	25.18	13.21	6.61	5.54	3.15	2.98	3.07	5.06	8.19	5.34	11.86	15.01
18	KANANASKIS	26.15	11.52	7.94	7.66	3.86	3.34	2.53	5.20	8.78	6.61	12.52	15.88
19	LACOMBE CDA	29.85	20.37	10.45	12.31	3.44	2.60	4.21	4.83	8.37	8.40	21.83	22.79
20	LAKE LOUISE	14.90	9.92	4.65	4.25	4.39	3.56	4.12	4.88	8.41	5.76	5.83	8.34
21	LETHBRIDGE CDA	33.53	26.19	12.37	11.01	4.20	4.41	3.00	4.25	8.65	8.05	17.03	20.09
22	MANYBER. CDA	34.84	29.56	17.34	11.21	5.13	4.86	4.17	5.28	8.87	7.53	16.03	18.67
23	MEDICINE HAT A	33.48	31.35	18.16	11.13	5.21	5.02	4.98	4.94	7.97	7.12	20.53	21.26
24	OLDS	33.27	22.59	10.69	11.20	4.23	3.35	2.80	4.67	8.26	7.83	18.92	21.06
25	PEKISKO	28.64	17.03	8.14	10.58	4.47	3.11	3.95	4.92	8.65	6.98	13.91	16.32
26	RANFURLY	29.45	19.19	11.05	12.67	4.06	3.06	4.75	4.96	8.38	7.20	20.26	22.40
27	RED DEER A	29.20	18.14	12.19	11.36	3.38	3.40	1.92	4.84	8.05	7.20	20.59	19.12
28	SION	33.50	24.04	10.63	13.40	5.27	3.72	5.24	5.00	10.21	9.77	21.42	25.53
29	LETHBRIDGE A	34.23	22.48	13.70	9.77	3.88	4.93	3.58	5.67	9.44	7.63	16.90	18.69
30	CORONATION	30.63	19.37	15.24	13.39	4.44	4.60	3.78	6.34	7.65	8.49	18.39	20.96
31	FORT CHIPEWYAN	20.68	26.68	17.51	14.25	8.04	3.71	2.09	3.69	5.16	6.32	12.80	19.72
32	FORT MCMUR. A	27.44	22.60	12.22	12.40	4.71	1.85	1.37	4.50	5.72	6.28	15.57	19.52
33	FORT VERMI. CDA	22.79	21.53	11.46	11.84	3.62	2.60	2.18	3.81	5.69	6.16	15.06	22.27
34	GRANDE PRA. A	36.12	21.21	10.76	10.57	3.06	2.20	1.73	4.25	6.02	5.53	21.03	22.33
35	HIGH LEVEL A	21.60	22.60	13.21	8.82	4.20	1.14	1.93	3.59	5.90	4.89	14.35	17.21
36	PEACE RIVER A	35.86	21.30	12.61	12.59	5.94	13.04	7.46	10.75	21.18	10.07	17.04	22.93
37	ROCKY MT HOUSE	31.03	25.94	9.41	9.68	4.52	4.31	3.50	4.58	8.18	8.23	19.88	19.99
38	SLAVE LAKE	31.84	26.60	10.76	11.26	2.70	2.27	2.08	3.02	6.27	6.00	18.03	26.15
	Average	29.66	21.74	11.21	10.26	4.30	3.67	3.38	4.92	8.26	7.23	17.08	19.99

Table 8. Monthly variance of minimum temperature (degree^2 C)

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	25.23	20.89	12.43	3.56	1.61	2.66	1.87	3.01	1.84	2.33	12.30	14.38
2	BEAVER MINES	34.63	32.13	10.68	5.26	2.25	2.96	2.23	4.06	3.08	4.77	12.53	19.23
3	BEAVERLO. CDA	34.23	24.07	12.41	4.97	1.31	1.17	0.84	1.20	1.92	3.00	18.13	26.63
4	BROOKS AHRC	30.65	29.03	11.94	3.45	1.55	1.65	1.06	1.28	2.17	3.09	10.85	22.15
5	CALDWELL	34.79	22.64	8.99	4.95	1.77	2.29	2.14	2.95	3.47	4.66	12.05	18.83
6	CALGARY INT'L A	27.74	25.14	12.26	3.72	1.68	1.76	1.23	1.88	2.12	2.91	13.04	18.76
7	CALMAR	28.28	27.41	16.52	5.33	1.95	2.49	1.44	2.37	2.67	4.82	16.09	21.25
8	CAMPSIE	26.42	23.27	14.93	3.35	1.43	1.77	1.51	2.23	1.95	3.08	15.03	21.29
9	CARDSTON	28.47	24.13	7.94	4.19	1.76	1.55	1.74	1.63	2.58	3.53	11.78	17.62
10	CARWAY	28.02	18.31	7.70	3.36	1.52	1.27	1.33	1.42	2.48	3.64	11.26	17.55
11	EDMONTON	33.20	30.92	16.92	5.48	4.44	5.20	4.44	6.02	5.14	5.13	15.87	20.26
12	EDSON	25.47	19.62	9.25	3.59	1.18	1.53	1.35	2.27	1.65	2.60	15.99	20.37
13	ENTRANCE	40.99	26.92	11.43	3.31	1.22	1.75	1.28	1.43	2.20	3.81	18.61	29.32
14	FAIRVIEW	36.31	31.98	14.09	7.10	1.65	2.27	1.94	3.20	3.57	4.39	19.41	27.54
15	GLEICHEN	27.62	24.88	11.74	3.69	1.93	1.45	1.03	2.27	2.20	3.37	11.14	17.24
16	HIGH RIVER	33.76	26.46	11.03	3.92	1.38	1.81	1.06	2.20	2.46	4.16	9.68	19.14
17	JASPER	30.29	17.51	7.63	2.98	0.88	1.25	0.99	1.39	1.66	1.78	12.88	16.90
18	KANANASKIS	30.67	19.78	11.55	4.11	1.23	1.09	0.78	1.39	1.94	3.12	12.92	19.23
19	LACOMBE CDA	24.47	23.03	14.16	4.76	1.88	2.24	1.22	2.33	2.47	3.06	12.44	16.29
20	LAKE LOUISE	24.58	17.48	7.13	4.06	1.22	1.58	1.84	2.21	1.45	2.69	10.78	13.44
21	LETHBRIDGE CDA	34.40	27.59	11.59	4.25	1.91	1.98	1.00	1.49	2.40	3.75	12.03	18.85
22	MANYBER. CDA	30.40	23.44	12.78	4.63	2.19	1.78	1.29	2.02	3.15	3.06	8.90	15.76
23	MEDICINE HAT A	33.84	32.28	15.03	4.08	1.62	1.82	1.70	1.67	2.53	3.28	14.54	20.89
24	OLDS	28.14	21.49	10.56	4.44	1.49	1.68	0.89	1.68	2.29	3.01	11.40	18.74
25	PEKISKO	34.96	23.55	9.68	4.81	1.58	1.55	1.05	1.71	1.83	3.61	11.87	22.86
26	RANFURLY	31.28	25.19	16.31	7.53	2.92	2.71	1.47	2.59	3.01	4.97	15.22	22.11
27	RED DEER A	24.54	18.08	14.75	4.14	1.20	1.72	1.00	1.85	1.98	2.41	13.89	18.13
28	SION	39.93	30.65	18.28	7.35	3.85	5.09	3.74	5.92	5.67	6.79	17.17	27.02
29	LETHBRIDGE A	34.10	21.31	9.59	3.37	1.28	1.68	0.97	1.60	2.33	3.30	14.05	22.38
30	CORONATION	25.20	18.79	14.69	4.55	2.25	1.98	1.20	2.12	2.41	2.94	13.65	18.01
31	FORT CHIPEWYAN	20.18	21.65	17.68	16.08	5.42	3.51	2.94	4.28	3.54	5.52	16.92	21.06
32	FORT MCMUR. A	29.30	23.06	18.73	9.39	2.81	2.59	1.45	2.47	2.48	2.31	17.15	21.45
33	FORT VERMI. CDA	29.51	31.78	28.57	18.64	4.61	6.25	4.77	4.94	5.54	9.72	21.59	25.21
34	GRANDE PRA. A	36.90	22.98	15.29	5.52	0.94	0.92	0.69	1.49	1.66	2.44	19.83	25.73
35	HIGH LEVEL A	28.04	20.52	16.44	4.63	1.34	0.54	1.26	1.86	1.77	2.10	20.25	17.23
36	PEACE RIVER A	39.68	25.98	17.52	5.94	1.25	3.31	2.02	3.24	4.62	2.38	24.37	32.76
37	ROCKY MT HOUSE	30.14	32.05	14.80	6.55	6.47	5.39	5.15	6.99	7.03	7.88	17.13	25.23
38	SLAVE LAKE	29.82	28.56	14.35	6.16	2.10	2.20	1.29	2.19	2.01	2.61	15.95	22.07
	Average	30.69	24.59	13.35	5.45	2.08	2.27	1.72	2.55	2.77	3.74	14.70	20.87

Table 9. Monthly variance of total rainfall (mm^2)

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	19.7	17.0	15.6	98.0	698.4	908.5	935.3	770.2	298.2	135.4	44.7	22.0
2	BEAVER MINES	82.5	24.1	13.8	419.2	2013.1	4072.7	1866.3	1375.9	1112.9	205.0	78.2	51.5
3	BEAVERLO. CDA	2.5	2.0	8.1	68.3	565.9	1548.0	1565.8	1141.1	575.7	108.5	70.7	10.6
4	BROOKS AHRC	2.5	1.6	11.9	229.5	729.9	1526.9	513.2	577.2	704.6	76.3	8.6	1.7
5	CALDWELL	6.9	0.7	12.0	368.4	2556.6	3762.1	1247.2	1573.0	1524.1	247.5	16.2	3.7
6	CALGARY INT'L A	0.7	1.4	13.2	171.0	980.0	2169.8	1588.2	1983.3	898.0	67.9	2.4	0.6
7	CALMAR	11.6	5.8	8.0	211.5	805.7	1896.2	1921.2	1489.9	704.6	128.1	17.9	6.4
8	CAMPSIE	8.7	0.7	19.3	204.5	683.0	1886.6	1333.2	1558.0	501.8	53.9	18.5	3.2
9	CARDSTON	3.4	0.5	70.8	314.2	2582.1	3083.9	1357.1	1469.2	1376.1	189.3	11.5	1.9
10	CARWAY	4.3	0.6	21.5	155.4	1307.1	3287.8	1384.6	1142.1	954.0	137.4	5.2	3.4
11	EDMONTON	8.4	1.3	8.1	148.3	815.1	1695.0	1823.0	1359.5	582.7	95.1	13.7	5.8
12	EDSON	5.0	2.0	15.8	141.5	963.0	2377.3	2165.3	1637.2	827.7	70.6	40.0	9.1
13	ENTRANCE	8.3	1.7	11.1	131.7	1086.3	2188.0	1942.1	1825.4	693.0	132.8	18.9	11.4
14	FAIRVIEW	1.8	0.9	44.7	60.4	850.6	1219.0	1458.9	845.1	384.1	83.3	29.7	8.0
15	GLEICHEN	3.9	17.3	6.4	227.8	872.4	1832.0	1231.8	1069.0	782.7	135.0	70.8	68.1
16	HIGH RIVER	0.3	0.1	29.1	315.5	1110.6	3974.0	1123.2	1435.1	956.8	131.6	3.0	0.2
17	JASPER	36.9	16.4	35.6	75.0	357.4	513.9	1036.6	825.6	369.6	198.5	87.1	42.3
18	KANANASKIS	12.6	1.8	6.4	295.4	1538.3	2692.2	1447.0	1560.7	1056.6	85.3	40.7	15.6
19	LACOMBE CDA	3.6	4.9	12.5	319.7	604.3	2095.5	1323.1	1328.5	670.5	96.1	11.0	7.0
20	LAKE LOUISE	6.4	20.4	31.6	73.6	360.5	717.8	788.3	776.0	493.7	245.8	21.1	3.3
21	LETHBRIDGE CDA	1.5	0.7	15.0	262.9	1037.8	2098.6	737.5	1014.4	826.5	164.9	8.4	4.2
22	MANYBER. CDA	6.3	1.3	16.1	176.6	812.7	1292.7	563.5	506.9	847.0	71.9	3.7	2.0
23	MEDICINE HAT A	0.8	0.8	23.1	158.0	762.0	1203.3	744.5	820.1	818.1	177.8	16.1	4.7
24	OLDS	3.7	1.3	18.2	273.9	782.6	2484.0	1653.2	2071.7	964.5	74.1	6.1	1.7
25	PEKISKO	14.5	1.4	11.0	340.3	2338.1	4525.3	1586.1	1876.2	1279.4	87.1	10.0	3.5
26	RANFURLY	3.0	2.3	10.0	278.3	593.7	1493.6	1367.7	1620.5	570.2	84.9	10.3	3.0
27	RED DEER A	5.6	1.9	6.0	90.2	612.7	1760.7	1402.4	1887.1	896.4	77.9	2.3	2.7
28	SION	8.3	2.4	14.7	136.0	795.7	2933.5	1685.4	1570.5	808.6	114.9	18.1	8.4
29	LETHBRIDGE A	0.4	1.7	9.7	251.8	933.9	1815.9	1202.0	1139.8	683.6	105.2	3.0	1.9
30	CORONATION	1.2	1.4	4.2	194.0	465.8	1032.7	1843.1	1201.6	588.7	53.0	8.7	0.8
31	FORT CHIPEWYAN	0.4	0.2	0.6	42.7	213.0	634.5	1567.1	565.2	518.3	158.2	8.4	3.6
32	FORT MCMUR. A	0.9	2.6	5.3	54.2	493.8	1362.3	1024.5	1303.9	715.0	187.9	23.0	4.4
33	FORT VERMI. CDA	5.3	2.0	4.4	101.2	451.5	944.7	1068.5	709.9	434.3	124.0	7.0	6.2
34	GRANDE PRA. A	4.2	1.7	4.1	70.2	401.7	1967.8	1686.7	1346.5	595.6	97.6	32.4	6.9
35	HIGH LEVEL A	0.3	0.6	1.7	85.0	348.4	928.0	503.5	928.0	370.9	155.0	1.3	0.8
36	PEACE RIVER A	1.0	0.5	1.7	76.4	449.0	1422.8	1083.3	757.1	755.3	66.0	27.5	2.3
37	ROCKY MT HOUSE	8.6	1.0	5.2	111.2	1095.2	2462.9	2308.7	1923.7	1131.0	113.6	11.7	2.4
38	SLAVE LAKE	10.7	3.9	27.6	120.2	483.2	1705.5	1331.9	1142.1	566.9	123.5	33.9	8.7
	Average	8.1	3.9	15.1	180.3	909.2	1987.3	1352.9	1266.5	758.9	122.7	22.2	9.1

Table 10. Monthly variance of total snowfall (mm^2)

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	692.2	427.8	270.9	233.9	241.6	18.4	0.6	1.0	87.8	251.4	576.4	876.6
2	BEAVER MINES	983.9	536.3	568.7	1152.7	392.1	57.5	0.0	20.5	318.1	841.7	887.3	1148.7
3	BEAVERLO. CDA	711.1	320.5	196.4	202.2	46.0	42.4	0.0	18.1	85.8	267.9	422.6	437.6
4	BROOKS AHRC	174.1	57.4	137.8	197.7	14.8	2.1	0.0	3.1	29.3	106.2	110.3	156.3
5	CALDWELL	889.2	613.2	703.0	1405.4	434.8	92.7	1.1	0.0	437.0	800.6	885.9	935.1
6	CALGARY INT'L A	118.2	110.7	151.3	234.3	207.6	25.1	0.0	1.0	132.9	140.5	229.8	168.6
7	CALMAR	332.1	134.1	222.0	170.3	90.0	0.0	0.0	0.0	28.9	179.4	257.3	156.0
8	CAMPSIE	275.7	198.7	177.7	115.5	58.3	5.7	0.0	0.1	10.9	140.7	216.4	227.2
9	CARDSTON	557.3	197.0	494.7	623.9	244.9	10.3	0.0	0.0	100.6	365.2	538.8	457.9
10	CARWAY	320.5	399.3	488.8	768.3	248.6	50.0	0.1	13.6	266.3	606.7	420.9	440.0
11	EDMONTON	256.9	169.0	205.6	175.3	53.1	0.1	0.0	0.1	23.8	170.7	286.9	220.6
12	EDSON	542.7	257.4	199.5	281.6	72.1	0.0	0.0	0.0	90.3	234.6	345.4	282.4
13	ENTRANCE	516.2	251.7	223.7	330.0	47.5	0.0	0.0	0.0	57.6	255.9	271.5	327.6
14	FAIRVIEW	387.9	407.0	189.8	215.9	12.4	0.5	0.0	9.8	110.3	196.9	332.4	410.4
15	GLEICHEN	123.5	169.0	155.6	206.7	135.2	0.7	0.0	0.0	39.5	129.0	198.0	157.1
16	HIGH RIVER	180.3	149.8	340.4	576.6	115.3	35.0	0.0	1.3	88.3	225.8	241.7	323.1
17	JASPER	741.8	477.7	109.1	84.1	49.7	1.2	0.0	0.3	17.8	61.8	339.7	388.1
18	KANANASKIS	405.4	415.8	580.9	990.9	737.9	11.8	0.0	3.9	378.1	527.7	454.2	467.4
19	LACOMBE CDA	147.1	169.9	142.3	271.8	36.1	0.0	0.0	0.0	29.0	110.9	161.5	178.9
20	LAKE LOUISE	1773.1	1309.6	619.3	683.7	211.0	14.9	0.0	2.1	142.3	751.9	1769.3	1975.1
21	LETHBRIDGE CDA	243.9	134.5	198.5	457.2	28.7	5.5	0.0	0.0	153.9	259.8	252.1	235.3
22	MANYBER. CDA	258.2	212.4	232.3	409.2	14.1	3.7	0.0	0.0	28.5	96.0	158.3	215.2
23	MEDICINE HAT A	194.8	126.9	152.8	179.9	13.2	0.1	0.0	1.2	25.9	74.3	238.0	174.1
24	OLDS	203.6	98.8	163.4	239.9	94.8	1.4	0.0	0.0	89.1	180.9	226.4	173.0
25	PEKISKO	452.8	382.1	511.0	1366.2	562.0	84.9	0.2	9.5	353.2	542.6	595.0	659.2
26	RANFURLY	135.9	128.3	172.9	137.1	35.2	0.0	0.0	0.0	21.8	109.4	273.2	149.2
27	RED DEER A	205.1	98.0	139.2	166.3	37.1	0.3	0.0	0.2	42.4	149.2	159.2	149.3
28	SION	318.2	337.5	383.6	158.6	70.8	0.1	0.0	0.1	29.0	236.9	409.5	400.7
29	LETHBRIDGE A	228.0	152.6	227.0	517.6	70.5	13.8	0.0	9.1	290.2	253.8	303.6	226.4
30	CORONATION	239.5	127.7	189.4	161.4	25.1	0.0	0.0	0.0	30.5	144.8	86.4	174.6
31	FORT CHIPEWYAN	94.5	176.2	80.7	135.0	61.2	0.2	0.0	0.0	13.9	160.1	252.2	185.1
32	FORT MCMUR. A	150.5	172.8	182.2	129.3	21.7	0.0	0.0	0.0	55.6	115.0	289.3	158.5
33	FORT VERMI. CDA	148.4	130.2	203.3	175.4	14.6	0.6	0.0	0.0	10.7	146.9	132.4	139.9
34	GRANDE PRA. A	734.9	315.7	179.3	104.7	22.5	0.0	0.0	10.1	31.0	159.0	379.0	385.7
35	HIGH LEVEL A	140.9	126.4	222.5	69.3	129.4	0.0	0.0	0.1	65.8	281.4	264.9	163.0
36	PEACE RIVER A	256.9	251.7	132.0	97.4	33.4	0.0	0.0	0.6	32.3	88.4	171.7	218.0
37	ROCKY MT HOUSE	330.7	163.5	281.3	324.5	121.8	1.6	0.1	0.7	94.1	263.2	202.4	246.2
38	SLAVE LAKE	542.8	171.8	355.3	145.7	21.5	0.0	0.0	0.0	18.8	155.8	229.1	239.3
	Average	395.0	265.2	268.0	365.7	127.0	12.6	0.1	2.8	101.6	257.4	357.1	369.1

Table 11. Monthly variance of total precipitation (mm^2)

StnID	StnName	J	F	M	A	M	J	J	A	S	O	N	D
1	BANFF	578.9	318.9	260.1	276.6	1021.1	942.7	935.6	782.9	433.6	380.7	555.3	706.3
2	BEAVER MINES	1114.6	598.6	543.4	1384.4	2406.8	4204.1	1866.3	1375.3	1437.3	990.2	967.1	1272.6
3	BEAVERLO. CDA	518.9	289.3	182.7	269.2	616.0	1559.2	1565.7	1164.3	734.3	373.7	371.0	331.1
4	BROOKS AHRC	174.9	57.6	119.2	439.4	713.2	1498.4	513.2	573.4	751.8	131.9	121.6	149.1
5	CALDWELL	901.6	605.2	689.9	1730.2	2995.8	4048.4	1236.4	1573.1	2299.8	1208.8	908.8	946.9
6	CALGARY INT'L A	93.9	129.6	174.1	389.5	1375.9	2216.1	1588.1	1980.2	1169.6	204.0	227.0	133.7
7	CALMAR	362.6	145.8	233.3	399.8	906.8	1896.2	1921.2	1489.5	751.3	311.0	258.5	162.8
8	CAMPSIE	271.2	195.4	187.4	317.7	692.3	1854.9	1333.2	1559.6	512.1	170.7	238.1	227.2
9	CARDSTON	546.4	196.7	459.5	779.4	2613.8	3189.1	1357.1	1469.2	1593.7	628.7	512.1	448.4
10	CARWAY	327.4	398.6	470.6	842.0	1617.2	3413.8	1388.0	1148.5	1315.1	819.6	426.4	450.6
11	EDMONTON	220.5	152.8	201.6	297.7	845.8	1697.4	1823.0	1360.6	636.4	260.8	270.0	198.0
12	EDSON	309.4	171.0	113.0	405.9	963.2	2374.8	2165.3	1640.2	943.9	321.8	334.9	215.2
13	ENTRANCE	551.6	253.0	219.0	425.8	1134.5	2188.0	1942.1	1825.4	901.8	381.8	258.9	321.1
14	FAIRVIEW	335.0	395.2	198.2	271.3	890.7	1217.8	1458.9	875.6	584.2	236.3	355.3	396.1
15	GLEICHEN	134.2	199.8	149.9	443.9	900.1	1873.5	1231.8	1069.0	915.2	293.5	236.3	194.0
16	HIGH RIVER	183.0	151.3	332.6	812.0	1184.2	4025.0	1123.2	1426.7	1049.9	417.6	242.4	325.3
17	JASPER	569.5	470.7	131.4	140.6	367.7	512.6	1036.6	824.3	386.8	253.3	258.4	321.7
18	KANANASKIS	469.9	428.8	559.8	1032.9	2094.1	2994.8	1447.0	1600.0	1603.6	606.3	408.9	483.8
19	LACOMBE CDA	142.0	169.3	158.5	544.4	645.2	2095.5	1323.1	1328.5	751.4	204.6	165.6	158.2
20	LAKE LOUISE	1830.7	1322.2	644.9	731.6	522.3	740.0	792.4	780.2	571.1	1255.6	1757.0	1978.4
21	LETHBRIDGE CDA	138.6	161.5	179.0	611.1	1077.9	2144.9	737.5	1014.4	919.0	462.0	242.2	164.6
22	MANYBER. CDA	251.9	217.1	228.4	635.8	846.1	1301.0	563.5	506.9	884.9	188.9	161.8	212.6
23	MEDICINE HAT A	149.7	133.9	159.9	373.0	829.3	1204.8	744.5	822.2	877.4	236.8	218.4	144.4
24	OLDS	223.5	102.7	186.1	508.1	886.5	2473.8	1653.2	2071.3	1247.1	259.7	225.2	173.3
25	PEKISKO	513.8	381.6	497.0	1383.8	2531.6	4644.0	1589.3	1904.9	1850.1	598.7	586.9	652.7
26	RANFURLY	133.1	137.3	185.7	458.6	618.8	1494.7	1367.7	1620.0	587.5	213.7	281.1	149.7
27	RED DEER A	169.8	91.8	124.0	282.8	623.3	1778.5	1397.3	1884.0	969.4	204.0	143.1	117.7
28	SION	323.8	336.3	375.7	282.7	879.8	2937.6	1685.4	1570.5	837.0	363.0	399.8	361.7
29	LETHBRIDGE A	151.3	171.5	162.2	587.5	1046.1	1913.3	1202.0	1134.6	921.5	515.3	289.3	155.9
30	CORONATION	165.8	102.8	135.2	308.0	454.6	1032.7	1843.1	1201.6	632.7	185.6	59.5	113.0
31	FORT CHIPEWYAN	93.6	171.8	83.0	162.8	273.0	637.7	1567.1	565.2	550.4	396.9	224.7	178.8
32	FORT MCMUR. A	122.9	129.5	131.9	164.5	531.3	1336.8	1018.2	1280.3	770.8	341.0	167.1	123.2
33	FORT VERMI. CDA	146.8	125.0	188.7	245.3	500.6	943.3	1068.5	709.9	444.0	281.1	135.0	143.7
34	GRANDE PRA. A	532.3	248.0	110.0	153.6	439.0	1967.8	1716.7	1342.0	639.5	278.6	292.2	312.6
35	HIGH LEVEL A	82.5	99.2	159.7	131.1	417.0	928.0	503.5	927.3	424.5	484.7	220.5	143.9
36	PEACE RIVER A	197.0	155.5	93.4	109.2	538.9	1422.8	1083.3	764.7	831.0	183.8	141.0	181.6
37	ROCKY MT HOUSE	277.5	141.6	247.5	427.1	1301.4	2426.9	2304.5	1922.3	1461.7	350.7	164.9	185.8
38	SLAVE LAKE	476.0	186.9	371.6	210.3	466.4	1748.5	1325.6	1128.0	599.2	276.1	278.3	240.0
	Average	362.8	256.4	253.9	499.2	1020.2	2023.1	1353.1	1268.9	915.5	401.9	344.9	346.7

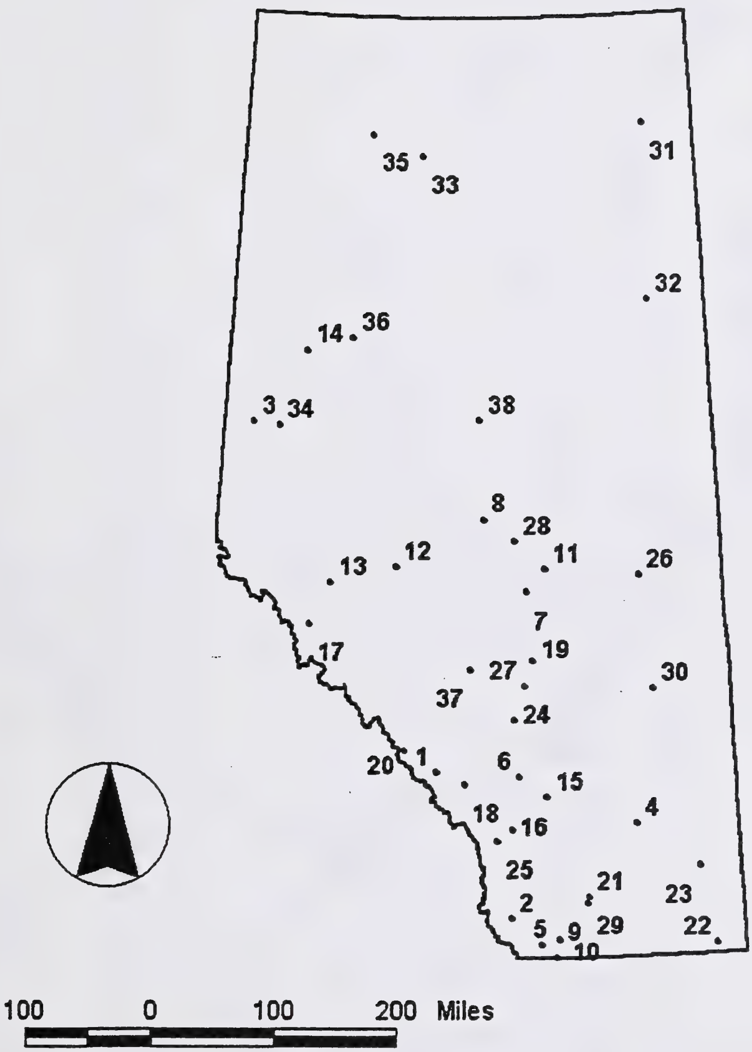

Figure 1. A map of the selected climate stations

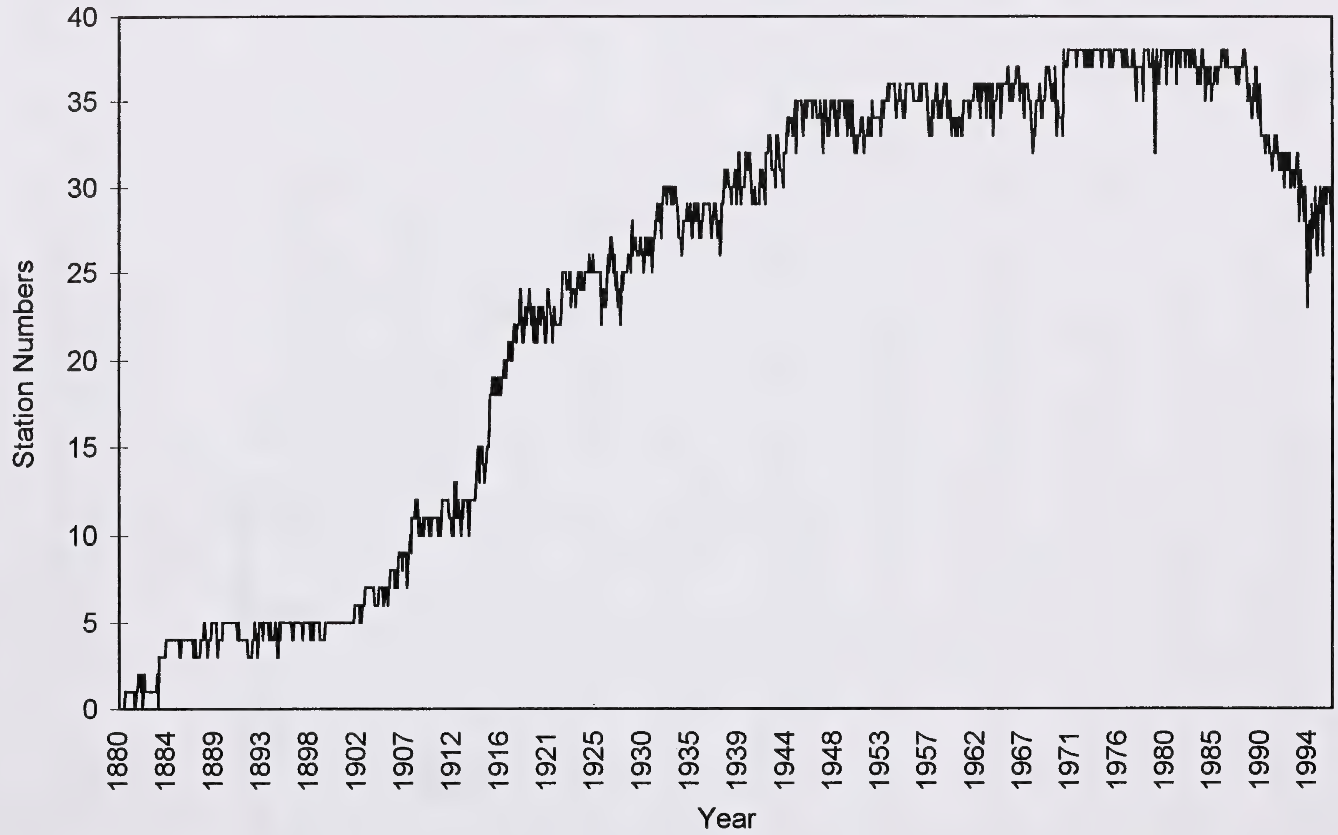

Figure 2. Number of stations measuring temperature

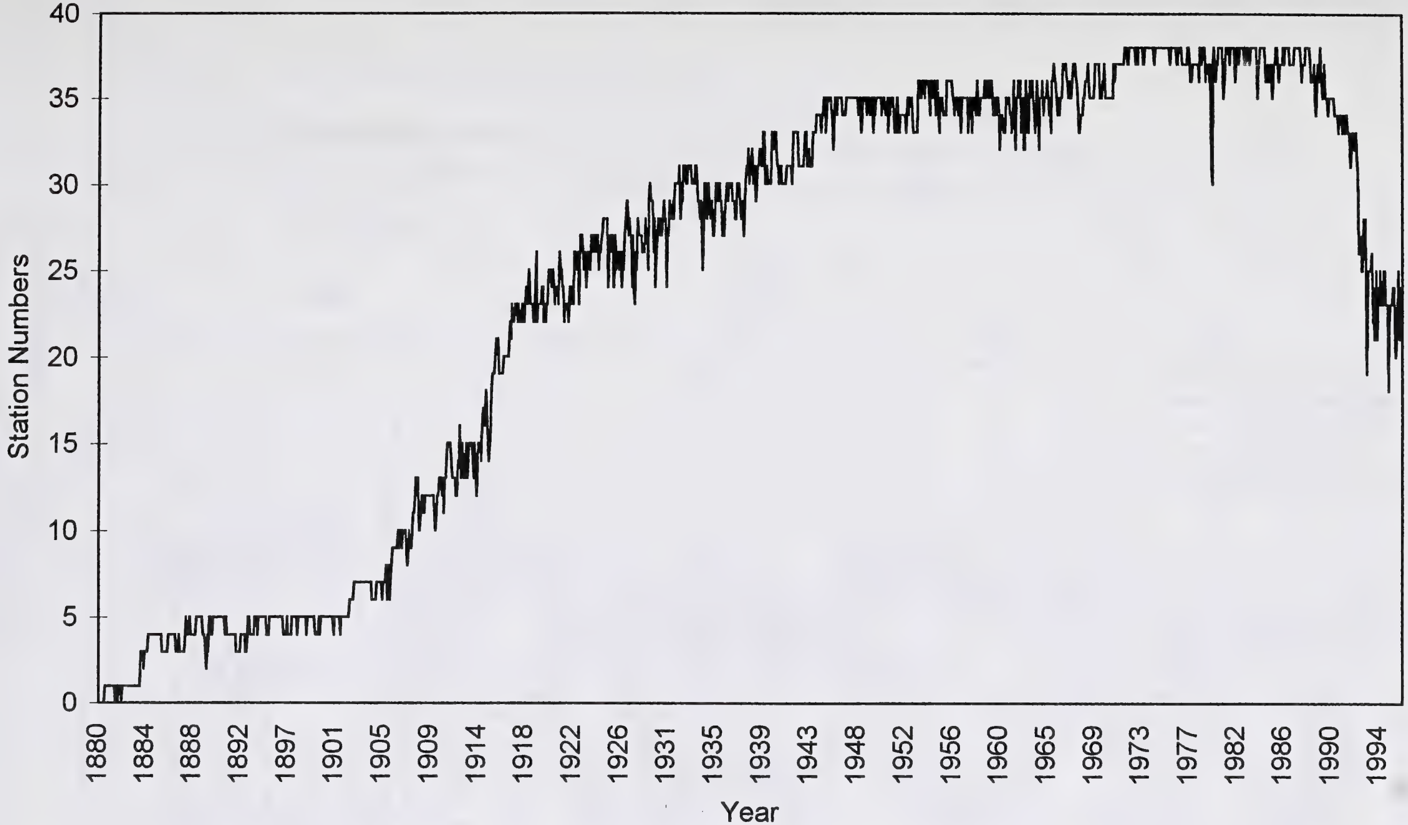

Figure 3. Number of stations measuring precipitation

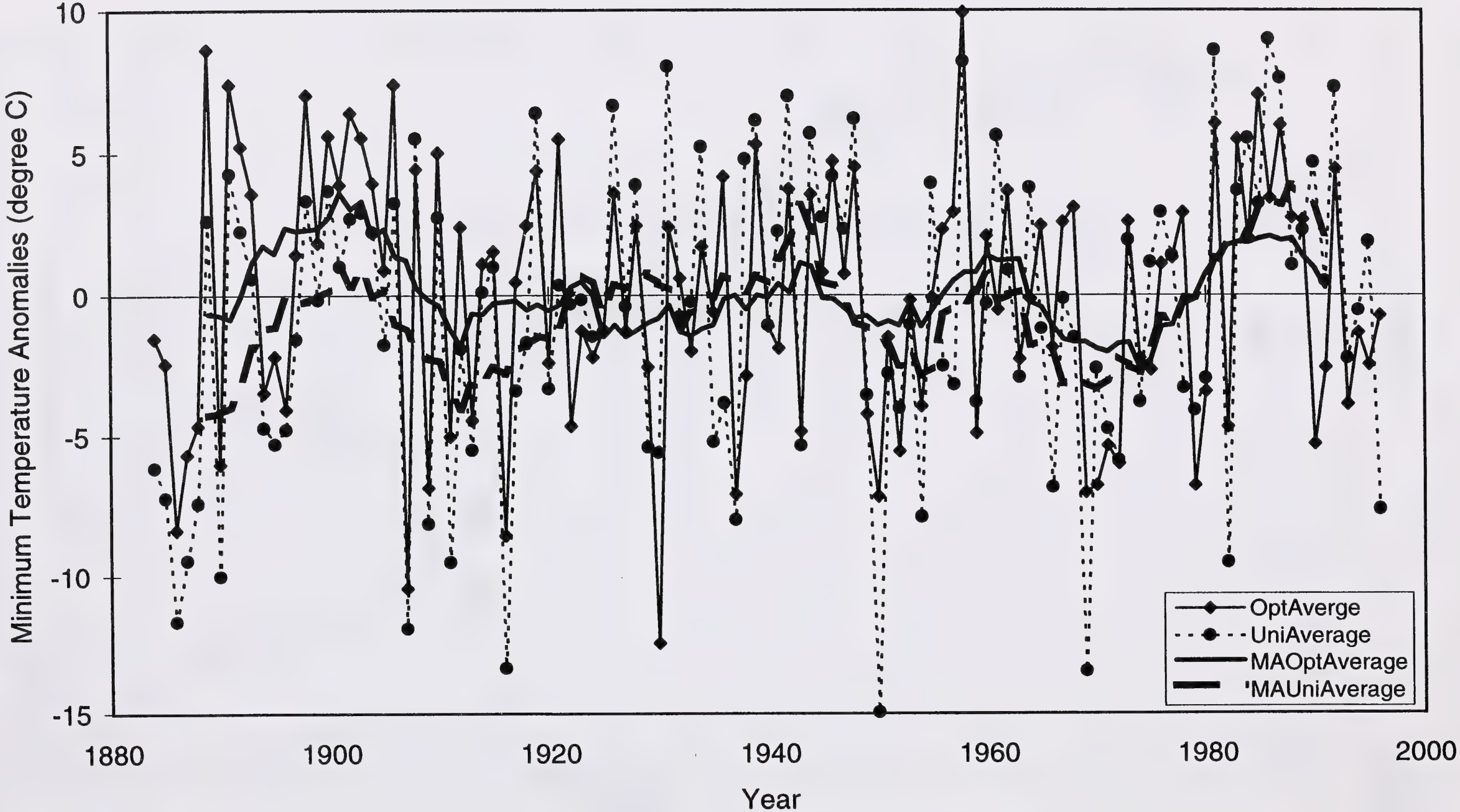

Figure 5. Uniform and optimal averages of January minimum temperature anomalies smoothed with the 11-year running mean.

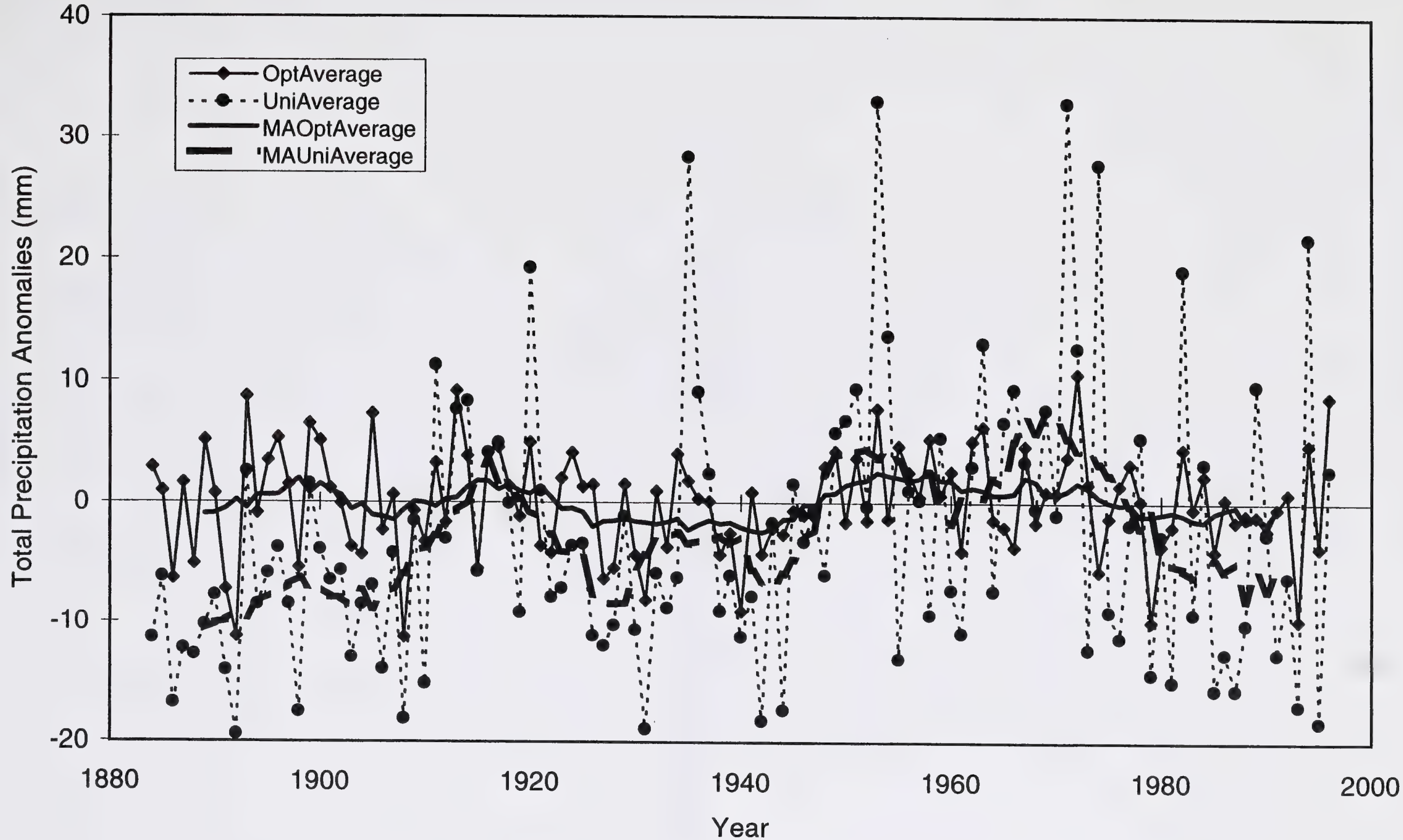

Figure 6. Uniform and optimal averages of January
total precipitation anomalies smoothed with the 11-year running mean.

APPENDIX B: THE MATHEMATICS OF THE OPTIMAL AVERAGE

Appendix B

Derivation of the optimal averaging scheme

In this appendix we use the temperature field as an example to illustrate our optimal method.

B.1 Weighted estimator of the averaged anomalies

We wish to measure the regional averaged temperature $\bar{T}_\tau(t)$ time averaged through the interval τ centered at t over the region R. The true value of this quantity is

$$\bar{T}_\tau(t) = \frac{1}{A}\int_R T_\tau(\hat{\mathbf{r}}, t)\, dA \tag{B.1}$$

where

$$T_\tau(\hat{\mathbf{r}}, t) = \frac{1}{\tau}\int_{t-\tau/2}^{t+\tau/2} T(\hat{\mathbf{r}}, t')\, dt' \tag{B.2}$$

is the τ-length averaging. The value of τ can be a month, several months (for seasonal averages), a year (for annual averages), or several years. In the above formulas, $\hat{\mathbf{r}}$ is a vector that determines the position of the point in question, $T(\hat{\mathbf{r}}, t)$ is the temperature at $\hat{\mathbf{r}}$ and t, dA is the integration area element and A is the area of the region R, i.e. Alberta.

Departures of the τ-average from the ensemble average are due to natural variability. Such a departure is called an anomaly:

$$\Delta T_\tau(\hat{\mathbf{r}}, t) \equiv T_\tau(\hat{\mathbf{r}}, t) - \langle T_\tau(\hat{\mathbf{r}}, t)\rangle \tag{B.3}$$

where $\langle T_\tau(\hat{\mathbf{r}}, t)\rangle$ denotes the ensemble average of $T_\tau(\hat{\mathbf{r}}, t)$. Similarly, we can define an anomaly of the Alberta average temperature:

$$\Delta\bar{T}_\tau(t) \equiv \bar{T}_\tau(t) - \langle T_\tau(t)\rangle. \tag{B.4}$$

By definition

$$\langle \Delta\bar{T}_\tau(t)\rangle = 0. \tag{B.5}$$

In what follows we will deal with the anomaly field and its Alberta average. To keep the notation simple we drop the prefix Δ.

The global average temperature anomaly may be estimated from the data streams collected from a given network of N stations $\{\hat{\mathbf{r}}_j, j = 1, 2, 3, \cdots, N\}$ by the estimator

$$\hat{\bar{T}}_\tau(t) \equiv \sum_{j=1}^{N} w_j T_\tau(\hat{\mathbf{r}}_j, t) \tag{B.6}$$

where w_j is the weight assigned to the j^{th} station. We impose the no-bias constraint on the weights

$$\sum_{j=1}^{N} w_j = 1. \tag{B.7}$$

Now we may form the mean square error (MSE)

$$\epsilon^2 = \langle(\bar{T}_\tau - \hat{\bar{T}}_\tau)^2\rangle \tag{B.8}$$

where ϵ^2 is a function of the weight vector $\mathbf{w} = \{w_j\}$. A natural question is what is the size of ϵ^2 and how does it vary for different choices of the station network $\{\hat{\mathbf{r}}_j\}$ and of the weight vector $\mathbf{w}$. In particular, one wish to know the best choice of $\mathbf{w}$, in the sense of minimum ϵ^2, for a given configuration $\{\hat{\mathbf{r}}_j\}$, since the latter represents the locations of historical stations, like the 38 stations used in our study.

Expanding the formula for the mean square error leads to

$$\begin{aligned}
\epsilon^2 &= \langle(\bar{T}_\tau - \hat{\bar{T}}_\tau)(\bar{T}_\tau - \hat{\bar{T}}_\tau)\rangle \\
&= \frac{1}{A^2}\int_R dA \int_R dA' \, \rho_\tau(\hat{\mathbf{r}}, \hat{\mathbf{r}}') - \\
&\quad - \frac{1}{A}\sum_{i=1}^{N} w_i \int_R dA \, \rho_\tau(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i) + \sum_{i,j=1}^{N} w_i w_j \, \rho_\tau(\hat{\mathbf{r}}_i), \hat{\mathbf{r}}_j)
\end{aligned}$$

where we have introduced the temporally smoothed covariance

$$\rho_\tau(\hat{\mathbf{r}}', \hat{\mathbf{r}}'') \equiv \langle T_\tau(\hat{\mathbf{r}}', t) T_\tau(\hat{\mathbf{r}}'', t)\rangle. \tag{B.9}$$

All second moment information about the anomaly field averaged over the interval τ is contained in this temporally smoothed covariance function.

B.2 Optimization of weights

We minimize the MSE subject to the no-bias constraint (B.7). This constrained minimization problem can be solved using the method of Lagrange multipliers. We simply extremize

$$J[\mathbf{w}] = \epsilon^2[\mathbf{w}] - 2\Lambda \left[\sum_{j=1}^{N} w_j - 1\right] \tag{B.10}$$

where Λ is a Lagrange multiplier and is always regarded as being a constant in the computational procedures following. This philosophy is the same as the method of optimal statistical averaging (e.g., Gandin, 1993). Taking the partial derivatives of $J[\mathbf{w}]$ with respect to the weights and the Lagrange multiplier and setting them individually to zero:

$$\frac{\partial J}{\partial w_i} = 0, \quad i = 1, \ldots, N, \tag{B.11}$$

$$\frac{\partial J}{\partial \Lambda} = 0. \tag{B.12}$$

Inserting the expression for ϵ^2 results in

$$\sum_{j=1}^{N} w_j \rho_T(\hat{\mathbf{r}}_i, \hat{\mathbf{r}}_j) - \Lambda = \frac{1}{A}\int_R \rho_T(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i) dA, \quad i = 1, \ldots, N, \tag{B.13}$$

$$\sum_{i=1}^{N} w_i = 1. \tag{B.14}$$

The above system is for $N+1$ unknowns, the N weights $\{w_i\}$ and the Lagrange multiplier Λ.

B.3 Computational algorithm

Attention is needed for the different lengths of the data streams: some stations started at 1880 and some at 1944 or later. The missing data for for a given station are replaced by the arithmetic average of the data from the other stations of the same month. For trend detection this procedure does not cause much signal deformation. Between 1880 and 1883, there were at most 2 stations in operation and for some months there were no data reports from either of the stations. Since the above arithmetic averaging to fill up the missing data needs at least one station, it is impossible to assess the climate condition with no data. Thus in the following we conduct our analysis from 1884. After this initial step of filling missing data, all the 38 stations have their data from 1884 to 1996.

According to the formulation in the above two sections (see equations (B.13) and (B.14) in particular), the crucial part is to calculate the covariance matrix $\rho_T(\hat{\mathbf{r}}_i, \hat{\mathbf{r}}_j)$ and the average $\frac{1}{A}\int_R \rho_T(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i) dA$. Since it is not possible to conduct true repeated climate experiment, the ensemble is replaced by discrete realizations over the years. Hence, $\rho_T(\hat{\mathbf{r}}_i, \hat{\mathbf{r}}_j) \equiv \langle T_T(\hat{\mathbf{r}}_i, t) T_T(\hat{\mathbf{r}}_j, t)\rangle$ is approximated by

$$\rho_T(\hat{\mathbf{r}}_i, \hat{\mathbf{r}}_j) = \frac{1}{K}\sum_{k=1}^{K} T_T(\hat{\mathbf{r}}_i, k) T_T(\hat{\mathbf{r}}_j, k) \tag{B.15}$$

where K, in the unit [year], is the length of the longest data stream. In theory, if K is sufficiently large and the temperature field $T_T(\hat{\mathbf{r}}, t)$ is ergotic in time, the above should converge to the true covariance. But, due to serial correlation in each data stream, the above

expression sometimes can be far from convergence and hence causes some uncertainties of this method.

The average $\frac{1}{A}\int_R \rho_\tau(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i)dA$ basically measures the strength of the climate signal of a neighborhood of the station i and the area the station i can reach. In particular, if the anomaly field is isotropic, a reasonable empirical expression for $\rho_\tau(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i)$:

$$\rho_\tau(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i) = \sigma_i\sigma_0 \exp\left[-\alpha|\frac{\hat{\mathbf{r}} - \hat{\mathbf{r}}_i}{a}|^\beta\right] \tag{B.16}$$

where σ_i^2 is the variance of ith station and

$$\sigma_0^2 = \frac{1}{38}\sum_{i=1}^{38}\sigma_i^2$$

is the averaged variance, a is the correlation length, i.e. the length scale, of the field, α and β are empirical coefficients (see Vinnikov *et al.* (1990)). According to the results of Kim and North (1993) and Hansen and Lebedeff (1987), the length scale may vary from 700 [km] to 2000 [km] depending on the length of τ and whether the region R is land or ocean. Our e-fold-correlation tests support that $a = 700$ km for temperature and 220 km for precipitation in Alberta. The area of Alberta is 661,185 km^2.

We take the following approximation

$$\frac{1}{A}\int_R \rho_\tau(\hat{\mathbf{r}}, \hat{\mathbf{r}}_i)dA \approx \gamma\sigma_i\sigma_0\frac{\pi a^2}{A}. \tag{B.17}$$

In this expression, γ is a dimensionless constant equal to $1/(\pi e)$. The empirical values for a and γ can vary from region to region. The best way is yet to be found to tune these parameters.

Now the linear equations (B.13) and (B.14) can be solved to obtain the values of the weights $w_1, w_2, \cdots, w_N$ and the Lagrange multiplier Λ. With this result, one can compute and plot the weighted average of the climate anomalies.